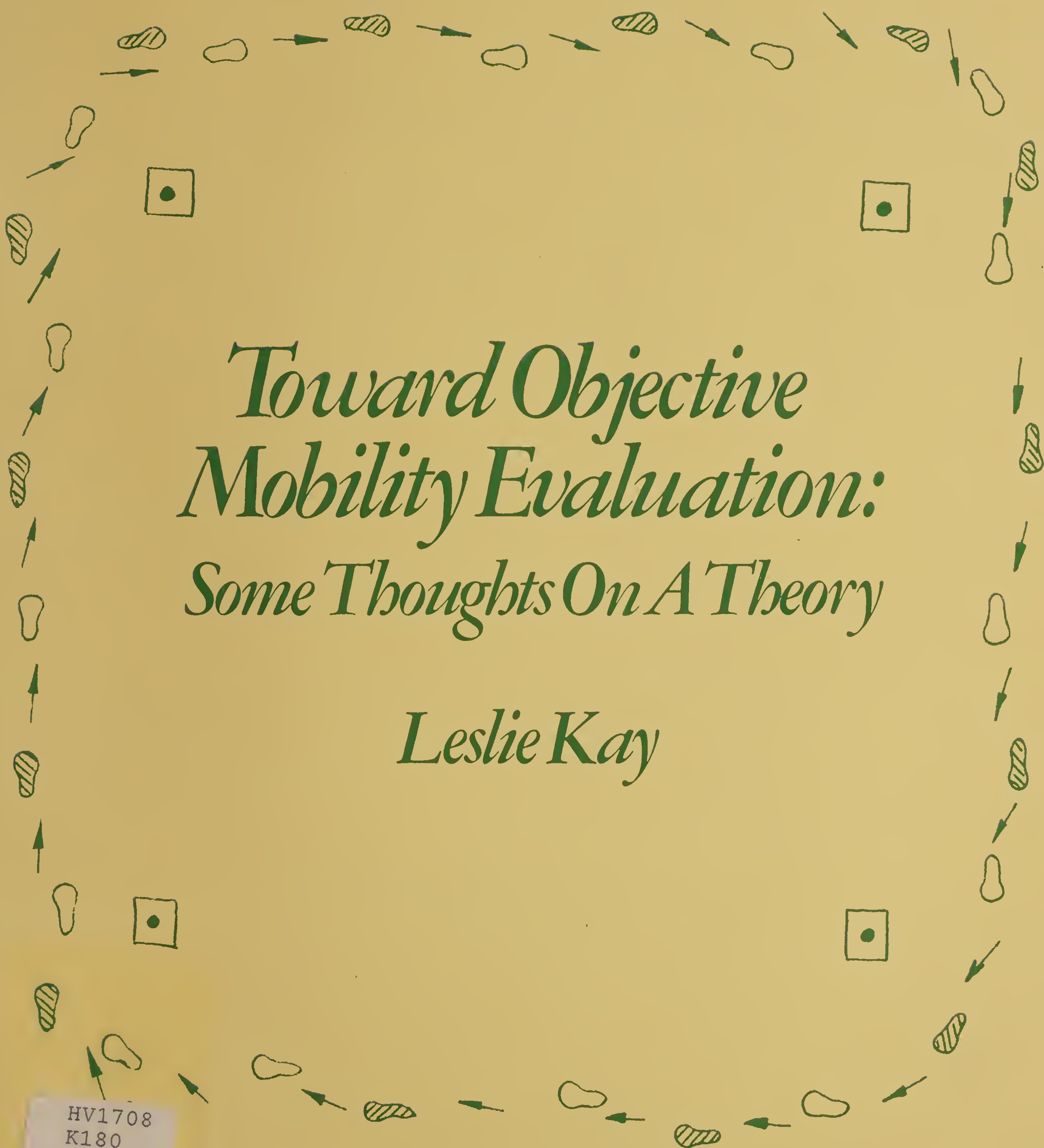

Toward Objective Mobility Evaluation: Some Thoughts On A Theory

Leslie Kay


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1. Introduction

The need for a theory of mobility has grown out of the efforts over the past 20 years or so to solve the problem of mobility for the blind through the use of sensory aids (Russell, 1970; Benjamin, 1970; Kay, 1970). Mann (1966) appears to be the first on record as voicing this opinion and there have been a number of attempts over the past few years at formulating such a theory (Leonard, 1968; Foulke, 1971). Little substantive progress is evident, however--at least in a form which can be used quantitatively to evaluate progress toward greater mobility for blind persons. This may be due to the very limited opportunity which normally exists for experimental observation in the rehabilitation field--for it is through prolonged observation that a theory is most likely to develop --or to the fact that the behavior of blind people in a mobility setting has been too variable for a pattern to become evident.

We do, of course, constantly observe our fellow beings walk about, but we pay little attention to how they do this in a cluttered environment. Hence we cannot call ourselves experts, even though we are competent practitioners of peripatetic mobility. We do, nevertheless, have little difficulty in picking out deviant mobility behavior enforced through some locomotive or perceptual handicap; we therefore know what to expect from a normal traveler even though we may not be able to specify it or explain why.

Some recent work evaluating a sensory aid (Kay, 1973a, 1973b) provided the opportunity, previously lacking, to observe in detail blind people as well as a few sighted subjects (under blindfold) learning various mobility skills and behavior patterns over a period of time. The interaction between student and teacher offered an opportunity to learn a great deal about the philosophy used in long cane travel as it is currently practiced by blind people. It was also possible to discuss with instructors their methods of teaching mobility using the long cane and electronic sensory aids in combination.

This experience helped to highlight many of the factors which determine a blind person's ability to be mobile. Even though the total picture is too complex to

view sharply as a whole, a course structure, shown in Figure 1, is emerging, one which forms the background against which a theory has to be developed.

2. Observation

Mobility by blind persons has been observed mainly by the orientation and mobility specialist (peripatologist) who has succeeded in training a number of blind persons to be independently mobile. (*Independent* is here taken to mean free of assistance from sighted persons except where the sighted person would also seek similar assistance.)

The teacher must constantly assess his student's progress, and over the years each has developed his own standards. Through having a common goal and having been trained in one of the few teacher training facilities, it is thought that a high degree of uniformity in these standards exists throughout the profession. Even so, a definition of mobility remains elusive and measurement of it reduces to highly subjective judgments. This was discovered during a special course, given to 11 experienced mobility specialists, on how to teach the use of a new sensory aid, one which was about to be evaluated. As a project, three small groups were formed and each was asked to determine what constitutes good mobility for an individual using the long cane, and how this could be measured. A week was allowed for preparation of a report.

Three quite different approaches were adopted by the groups and it was evident from the reports that unanimity of opinion did not exist. All did however feel that the individual student should be assessed on his own merits and many factors relating to the individual characteristics of the student were allowed to influence judgments. Objective measurement of mobility in a scientific sense was not thought to be viable.

This result was not unexpected, for it is no more reasonable to attempt an objective assessment of a blind person being taught mobility than an arts student composing an essay. (It will be shown that the two have much

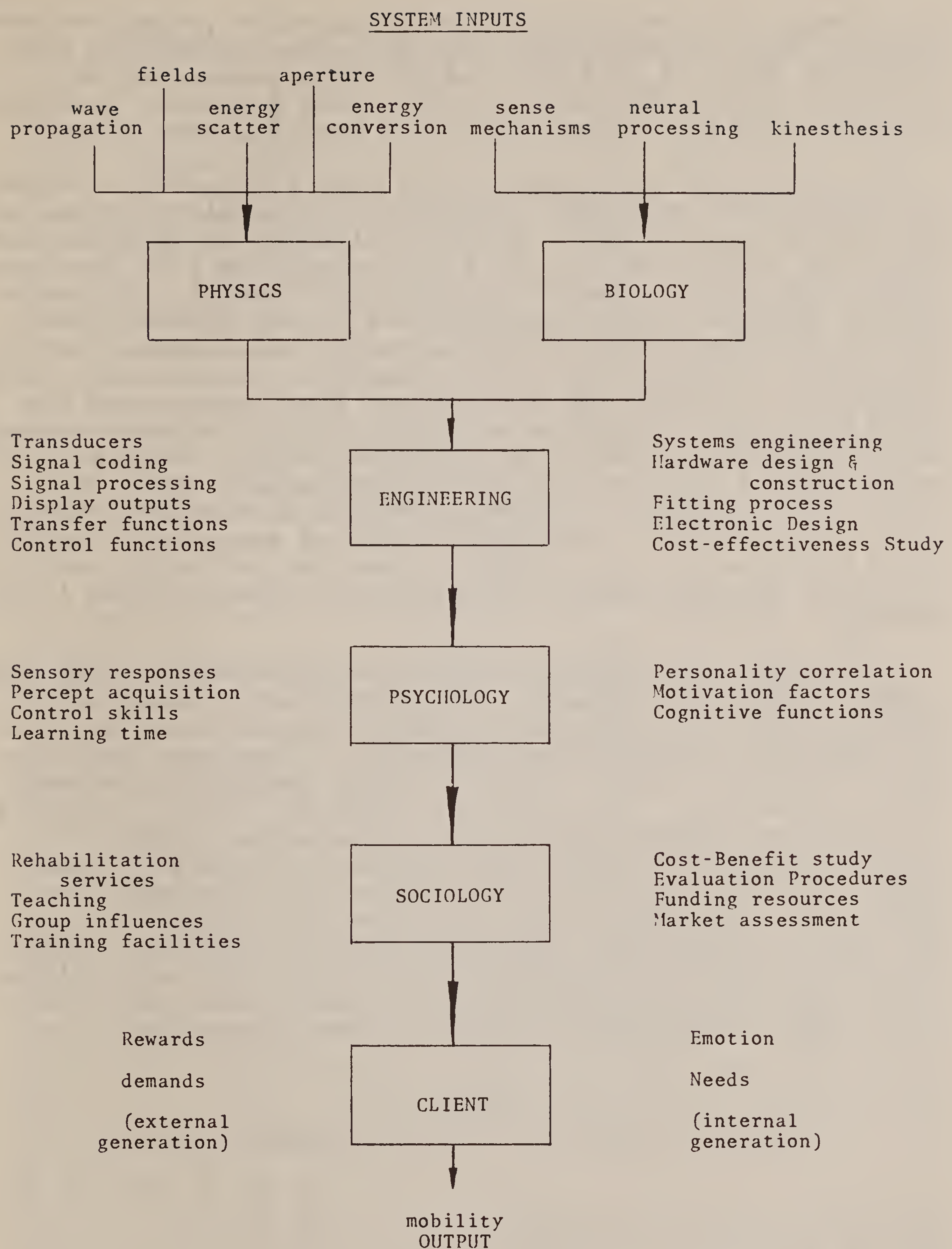


Figure 1. A Systems Approach Towards Mobility For The Blind.

in common.) It could not be expected, either, that teachers would be able to define mobility when the fundamental principles on which it is based had not been adequately researched. The techniques in current use have been developed by trial and error over a period of some 25 years or so.

A second project, presented to each group, was to develop some method for measuring the mobility of a blind person using the new sensory aid. The objective was to determine the extent to which a device, used in conjunction with the long cane, could alter a user's mobility performance. No satisfactory objective method emerged and it was apparent that each teacher preferred to rely upon his own judgment and experience. It was agreed that it would be best to use a questionnaire to collect the opinions of the teachers and the blind users and through an analysis of their answers attempt some objectivity. There were obvious dangers in this, but a better method could not be found which gained acceptance. Twenty-five teachers in three countries were to be involved in the evaluation of the sensory aid and approximately 150 blind people were to be taught to use the device in conjunction with the long cane or the dog guide (Kay, 1973a, 1973b; Airasian, 1973).

To assess the uniformity that one could expect from individual subjective judgments, the same teacher groups were shown a film of a few people using the sensory aid both during training and some time afterwards. They were asked to give a rating A, B, C, D, or E, to two particular subjects using the device. The result is shown in Table 1, together with written comments which were volunteered. Subject A (sighted under blindfold) was observed traveling in a suburban area leading to an intersection in a business area. There were few uncontrolled variables with which this subject had to contend and the route was well practiced under blindfold. Subject B (congenitally blind) was seen walking from a park area into and along the main street of a busy city. Many uncontrolled variables were encountered.

TABLE 1

Judgment of Mobility by Professional Teachers

	A	B	B-	C+	C	C-
Subject A (Sighted--Blindfold)	3	6	1			
Subject B (Congenitally Blind)	3	1	2	1	2	1

Comments: No comments were offered in writing concerning Subject A, but all agreed verbally that the performance was "very good." Concerning Subject B, instructor 1 gave a rating of A and commented "Have to judge performance and how user employed aid. There were cane faults but these cannot count in this case." Instructor 2, A, "but there was steady traffic flow throughout and very little pedestrian encounter to produce variation." Instructor 3, A, "if she was indeed congenitally and totally blind." Instructor 4, B, "Technique, a couple of defects; movement, generally smooth. No real way of checking sensory and navigational factors." Instructor 5, B-, "General overall performance seemed good; seemed tense initially and later developed more." Instructor 6, B-, "C for cane skills, B for sensory aid plus cane." Instructor 7, C+, no comment. Instructor 8, C, "Moved fairly fluidly but erratic in use of cane and aid." Instructor 9, C, "Typical congenital blind gait. Responses were more jerky. Lacked smoothness. Cane technique less than adequate." Instructor 10, C-, "More tense than previous subject."

Where the skill was clearly demonstrated to be good, the response was more uniform--although there is some difference of opinion on the letter grade which should be given. This is to be expected when an objective measure for a grade is not available. When the variables affecting performance were considerably increased, the spread of judgments was also increased and comments to justify the particular judgment were offered.

It would seem from all this that to be *measurable*, "mobility" must be reduced to a set of well-defined skills. The relationship between these skills and what may vaguely be termed "mobility" has to be established before more objective results can be obtained from real life settings. *Observation* of the "mobility" skills, around which a theory may ultimately be constructed, is still limited in that these skills are seen to remain too complex to measure. We really need a subset of skills so that only very simple tasks have to be attempted when measurement becomes possible; these skills, it is hoped, would remain meaningful in the mobility context.

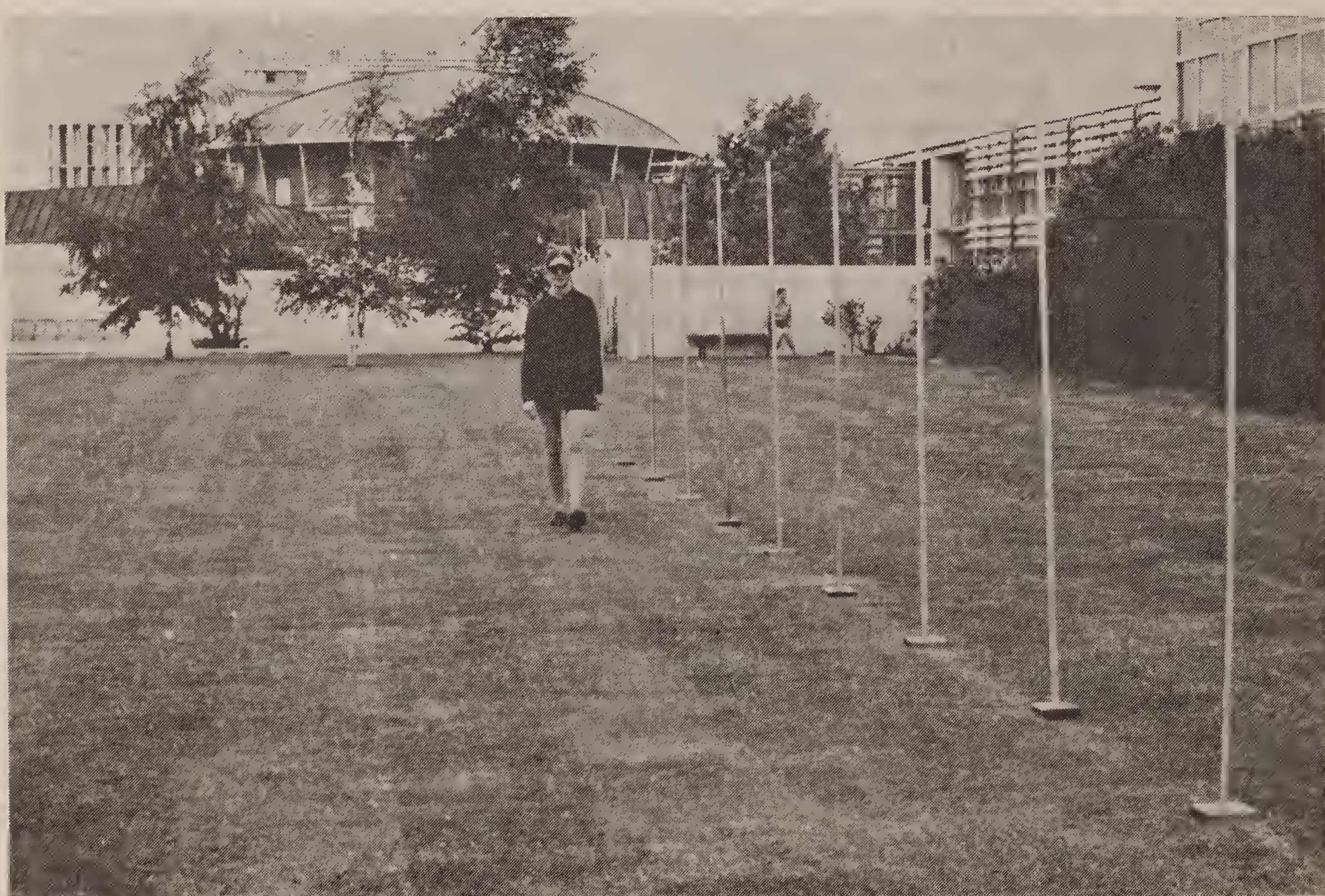
3. A Subset of Mobility Skills

In order to teach the "Kay" Sonic Torch, a series of lessons were devised by Elliott, et al. (1968) in which bamboo canes were used for a number of exercises on walking parallel to a "shoreline." Following this idea, lessons designed to teach the Binaural Sensory Aid used poles placed in various patterns so as to develop a student's ability to control his movements. An example of an advanced pattern is illustrated in Figure 2.

The following exercises are examples of what blind people have learned to do.

i) Walk up to a pole from a distance of several feet and grasp it (teaching distance and direction cues while attempting to maintain the body on a directed course with terminal reinforcement through proprioceptive feedback).

Figure 2. Exercises In Body Control Multiple Object Situation.



ii) Walk around poles placed at the four corners of a ten-foot square grasping each pole momentarily without stopping (teaching the combined effect of direction and distance change, as a pole is passed, through the kinesthetic feedback from both foot movement and hand contact with the pole).

iii) Walk around four poles forming a square, passing each at a distance of approximately two feet (teaching course construction through sensory aid input and proprioceptive feedback from the effect of locomotion over the ground).

iv) Walk along a row of poles spaced six feet apart (teaching the maintenance of a course relative to a shoreline and learning to correct course deviations smoothly).

v) Walk between two straight rows of poles spaced four feet apart (teaching control of body movement and the construction of a course in a cluttered environment which provides multiple signals).

vi) Walk in slalom fashion along a row of poles (teaching fine control of body movement and course planning in a varying spatial pattern).

Can these tasks involving "mobility" skills be used as the basis for measuring the subset of mobility skills which we apparently require for evaluation of performance? If this can be shown to be possible, the next step of relating these to real-life mobility can be attempted.

3.1 Observation of Skills

Blind people as well as a group of blindfolded sighted subjects were filmed performing tasks (i) to (vi). The latter group, executing tasks (v) and (vi) in succession, were viewed by a class of 58 university students who had no special knowledge of mobility as experienced by blind persons. They were asked to give each of five subjects a rating from zero (corresponding to performance like a blind person) to ten (corresponding to sighted performance). The task is illustrated in Figure 3 and the response from the judges is shown in Figure 4.

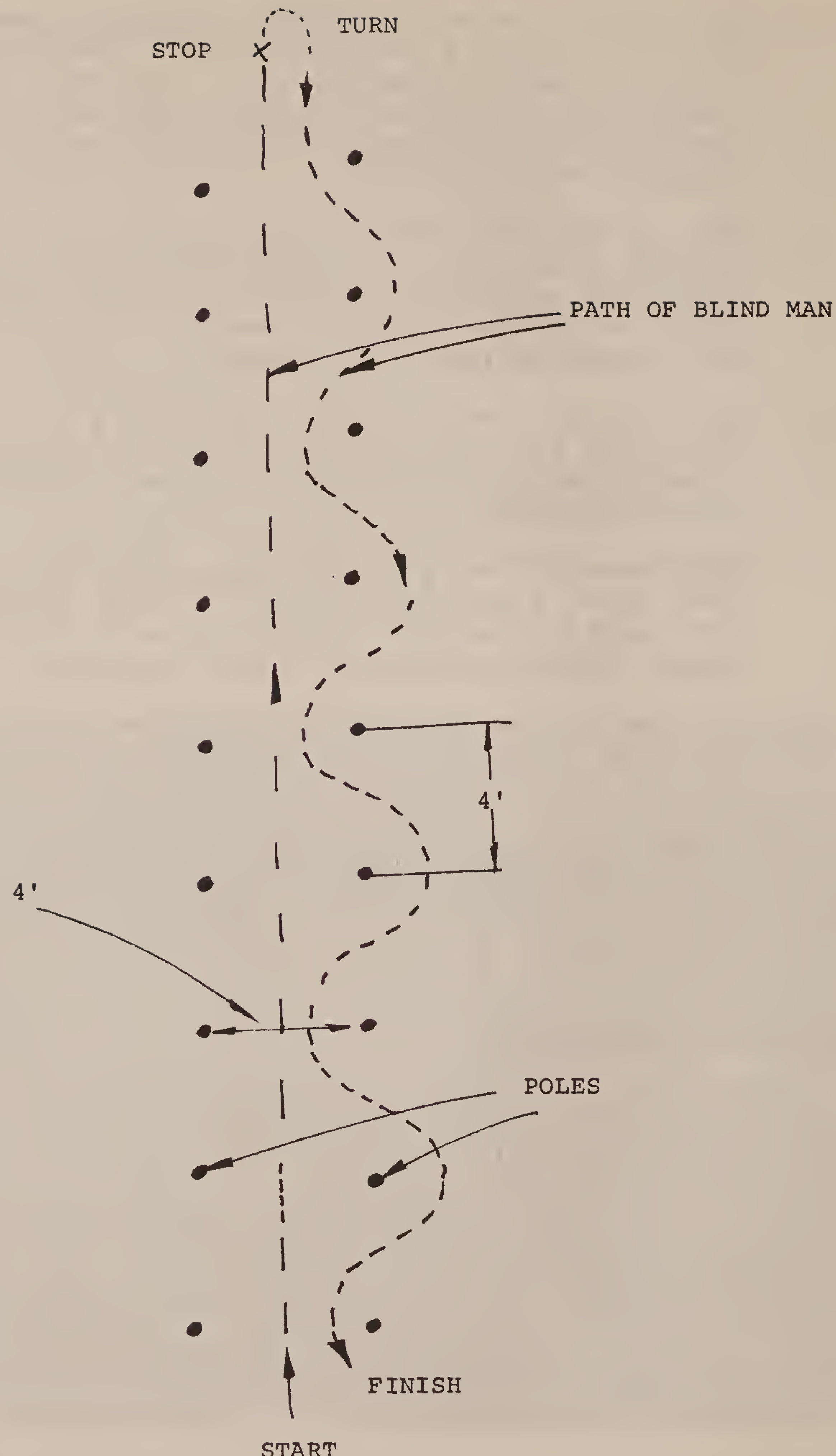


Figure 3. Mobility Task For Measurement Of Skills.

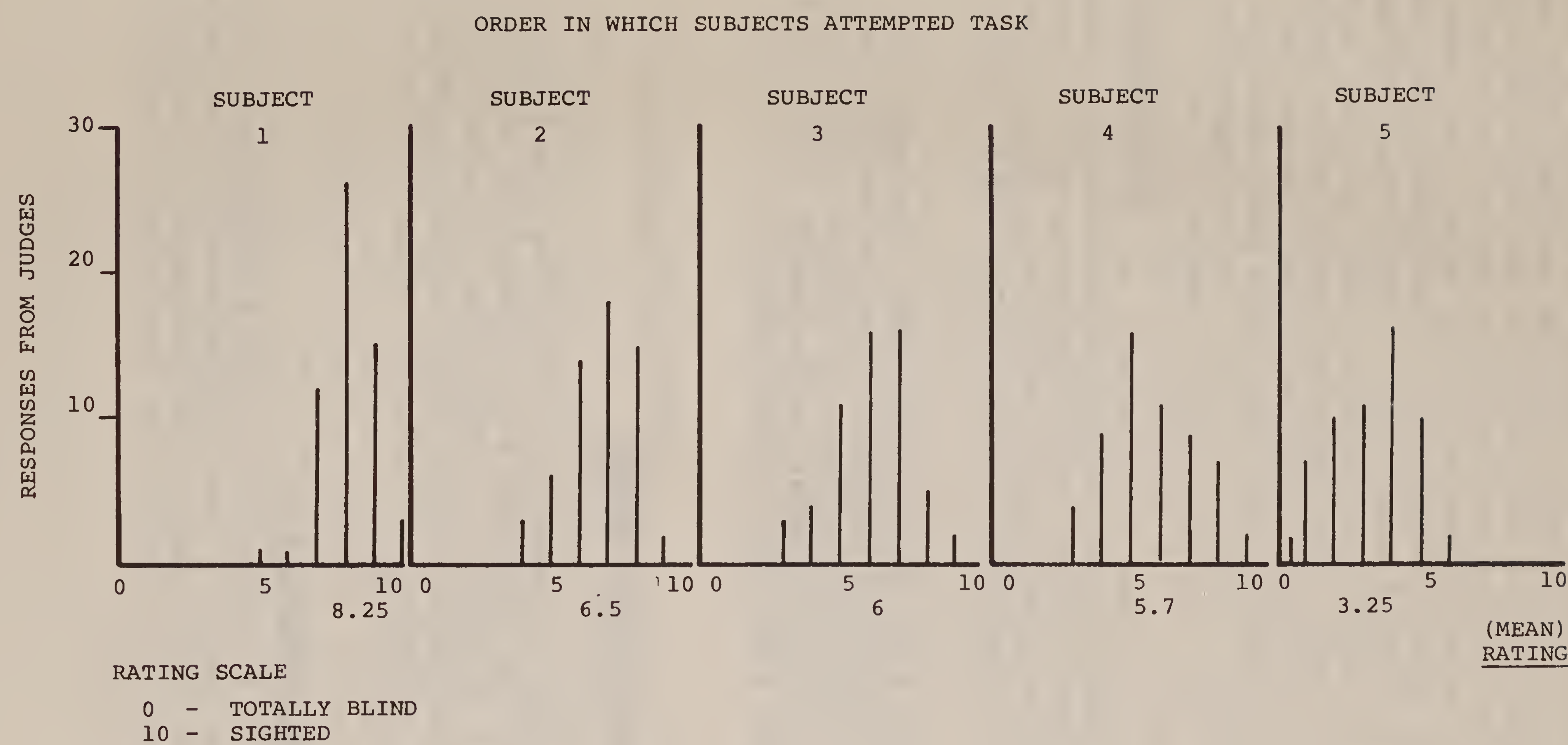


Figure 4. Responses From 58 Judges On Sighted (Blindfold) Subjects Negotiating Poles Of Figure 3.

We were concerned in this experiment with assessing the reliability--or uniformity--of the judgment of a number of individuals having tacitly made the initial assumptions that *sighted performance* will be judged equally by all, and that *blind performance*--which no one had seen--could be guessed equally well. It is apparent that the performance of Subject 1 was best. Three people thought it was as good as sighted performance and only two gave a rating as low as seven. As the mean rating of performance for each subject falls, the variances in the judgments increase, indicating the lack of a well-defined scale of performance. Subject 5 was clearly rated low and two judges rated the performance comparable with that of blind performance. The variables which influence judgments apparently increase considerably as the performance deteriorates, based on the subject's posture, gait, hand movement, pace, hesitation, search pattern, etc., and not all these variables were equally weighted. Sighted performance would be characterized by *normal* behavior in all these respects.

It would seem from this result that even when the task is well defined and executed in a controlled setting, individual behavior--which is variable--has a significant influence on judgments and simpler tasks must be used involving some form of measurement.

4. Measurement of Sub-skills

The most effective means for recording the performance of a subject in even the most elementary mobility situations is by filming it. Some film of totally blind persons executing tasks (i) to (vi), has been examined, frame by frame, and the steps of the subjects plotted (see Figures 5 through 8).

4.1 Grasping a Pole on Passing It

The movement of Subject 6 is shown approximately from the footsteps as they are made, together with the number of frames between each step. Head movement is shown by arrows, and no oscillation of the direction in which it pointed was noticeable.

The sequence, as plotted in Figure 5, is part of a number of times the subject walked around the triangle. It was not observed at the time the film was taken, that a pattern of movement for the feet had been established and that the action at each pole was very similar. The change in pace may be determined from the number of film frames between steps. While some detail is given in the figure, there is still little indication of the actual behavior. Only the film reproduces this realistically and, after analyzing it frame by frame, one is much more observant when subsequently watching the action replayed at normal speed.

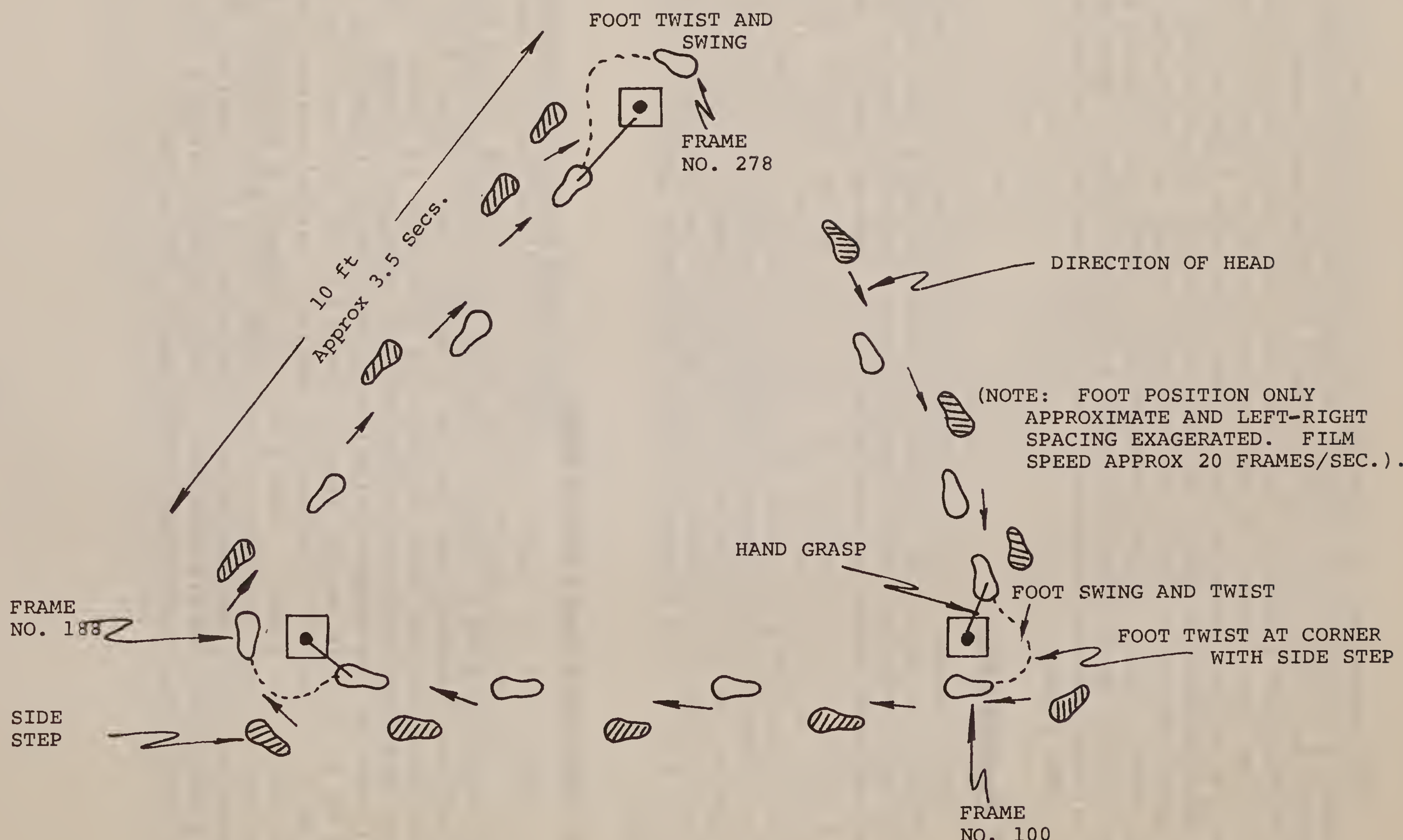
4.2 Passing a Pole

The movement of Subject 6 passing four poles forming a square is shown in Figure 6, where it will be seen that both head movement and foot movement are noticeably changed. The subject looks at the pole for a shorter period of time and there is no slacking of the pace at the turn. The difference in direction of the pole relative to that of the head is allowed to increase rapidly prior to reaching the pole, whereas in Figure 5 Subject 6 looked at the pole right up to the point where it was grasped. The pace between poles is increased considerably yet a pattern has still been established for the footsteps relative to the poles.

4.3 Walking Along a Row of Poles

Subject 6 is shown in Figure 7 walking past a row of poles 2.5 meters apart, then turning through 180 degrees and walking back. Here a pattern of footsteps could not have been established before filming; the subject approached the row from an initial distance of about 3 meters and immediately established a suitable course. The pattern of footsteps relative to the poles therefore seems to be a feature worth investigating. An interesting action is illustrated when the subject turned around and retraced her steps. There was no change in pace and the new course was quickly established. The head faced pole 7 on return only momentarily, otherwise it was held pointing slightly toward the row. This looked natural. A good pace was maintained throughout the action.

Figure 5. Blind Person Walking Round Poles Grasping Each Pole As It Is Passed.



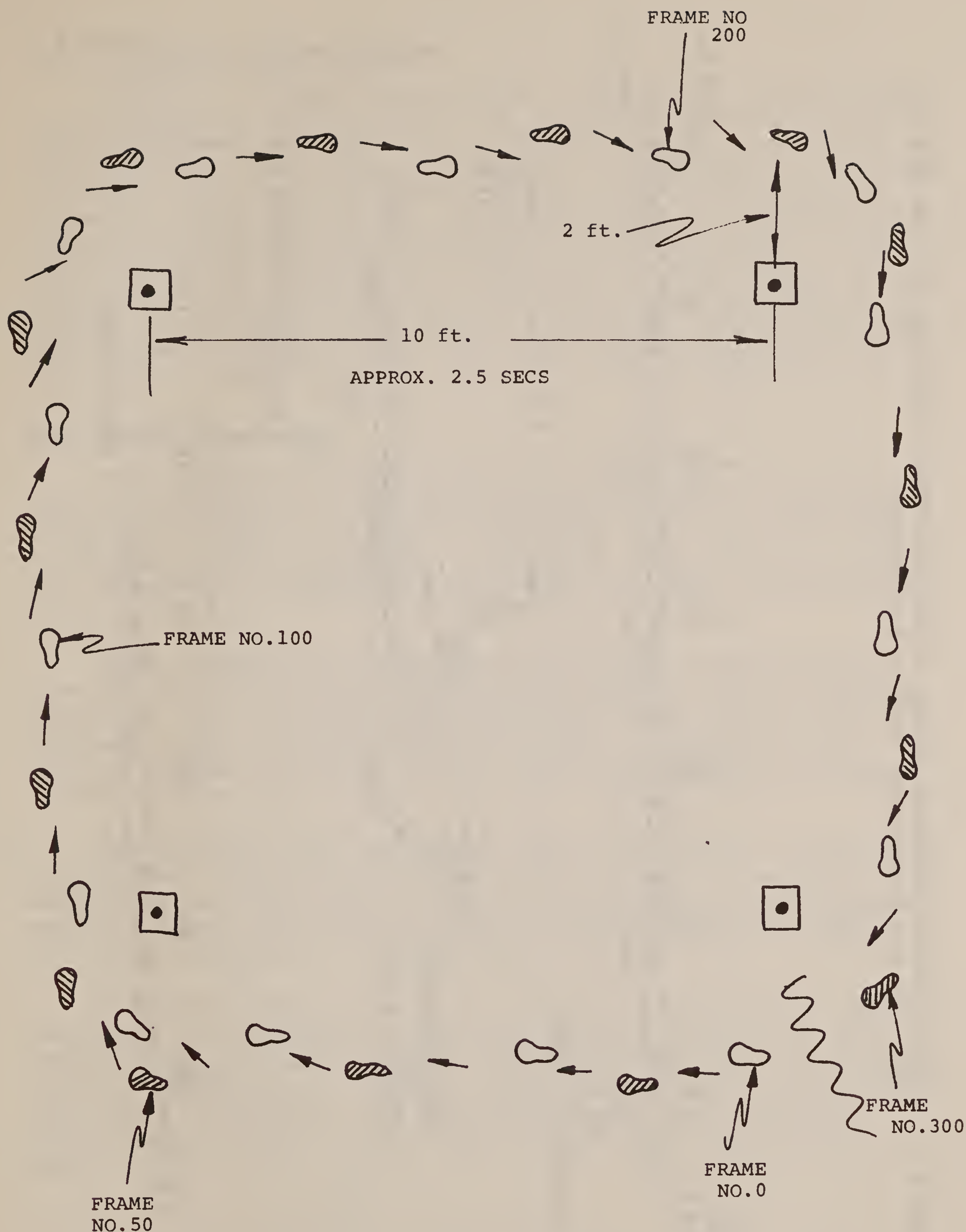
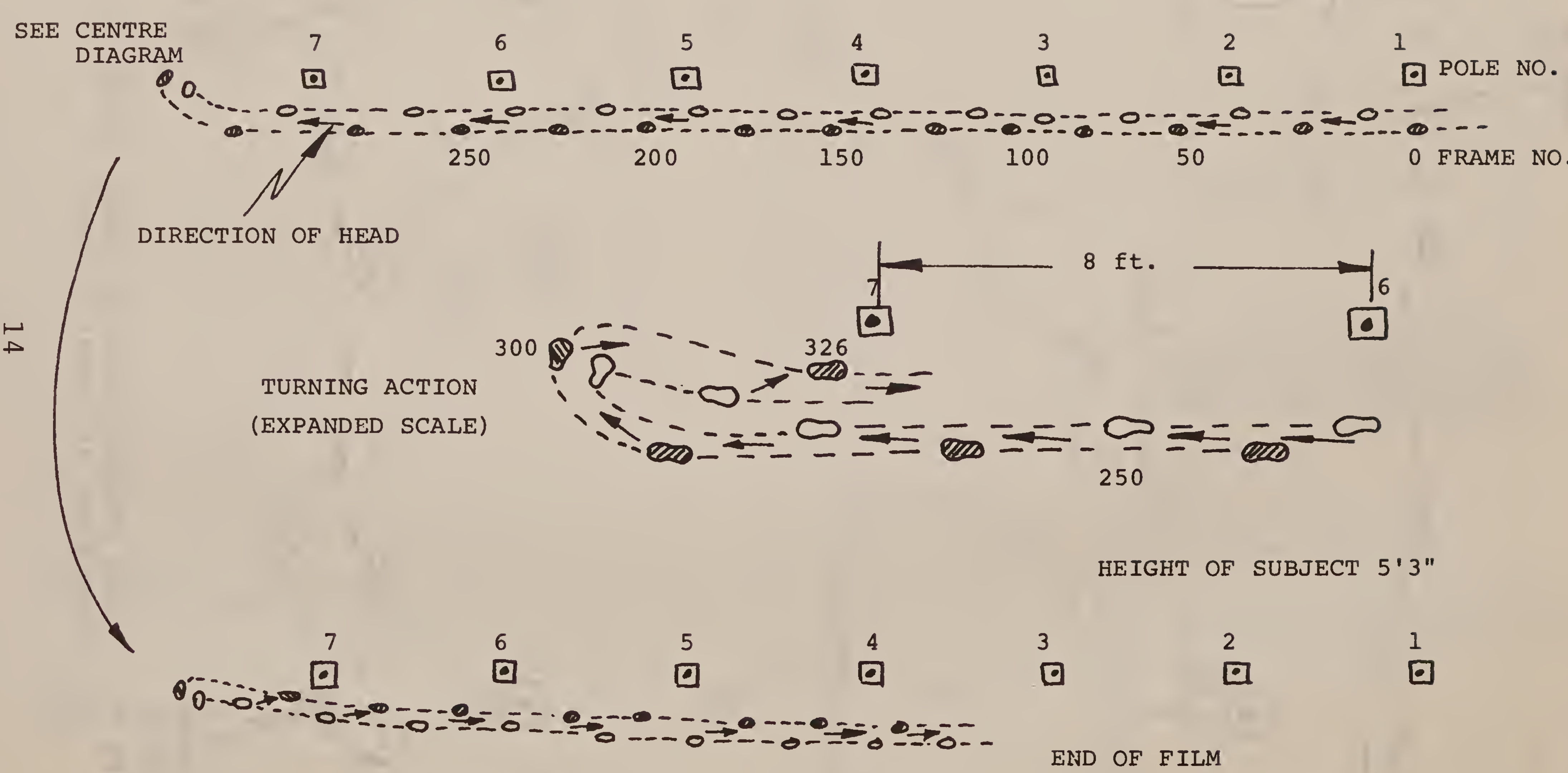


Figure 6. Blind Person Walking Round Poles To Pass Each At About 2 Feet

Figure 7. Blind Person Walking Along A Row Of Poles, Turning At The End Of The Row And Returning To The Beginning.



4.4 Walking in Slalom Fashion

Subject 7 walked along a row of poles in slalom fashion to the end of the row, then returned to the beginning following a similar pattern. Figure 8 shows the action while passing the first ten poles. A minor error was made when the subject's shoulder brushed pole 3; this seemed to be the only corrective feedback needed to ensure complete avoidance for the remainder of the exercise. Here the pattern of footsteps is much less regular relative to the poles. The head *slowly* oscillated from left to right as the poles moved from right to left in a regular pattern; the subject looked at the *next* pole only momentarily on passing the near one.

4.5 General Comment

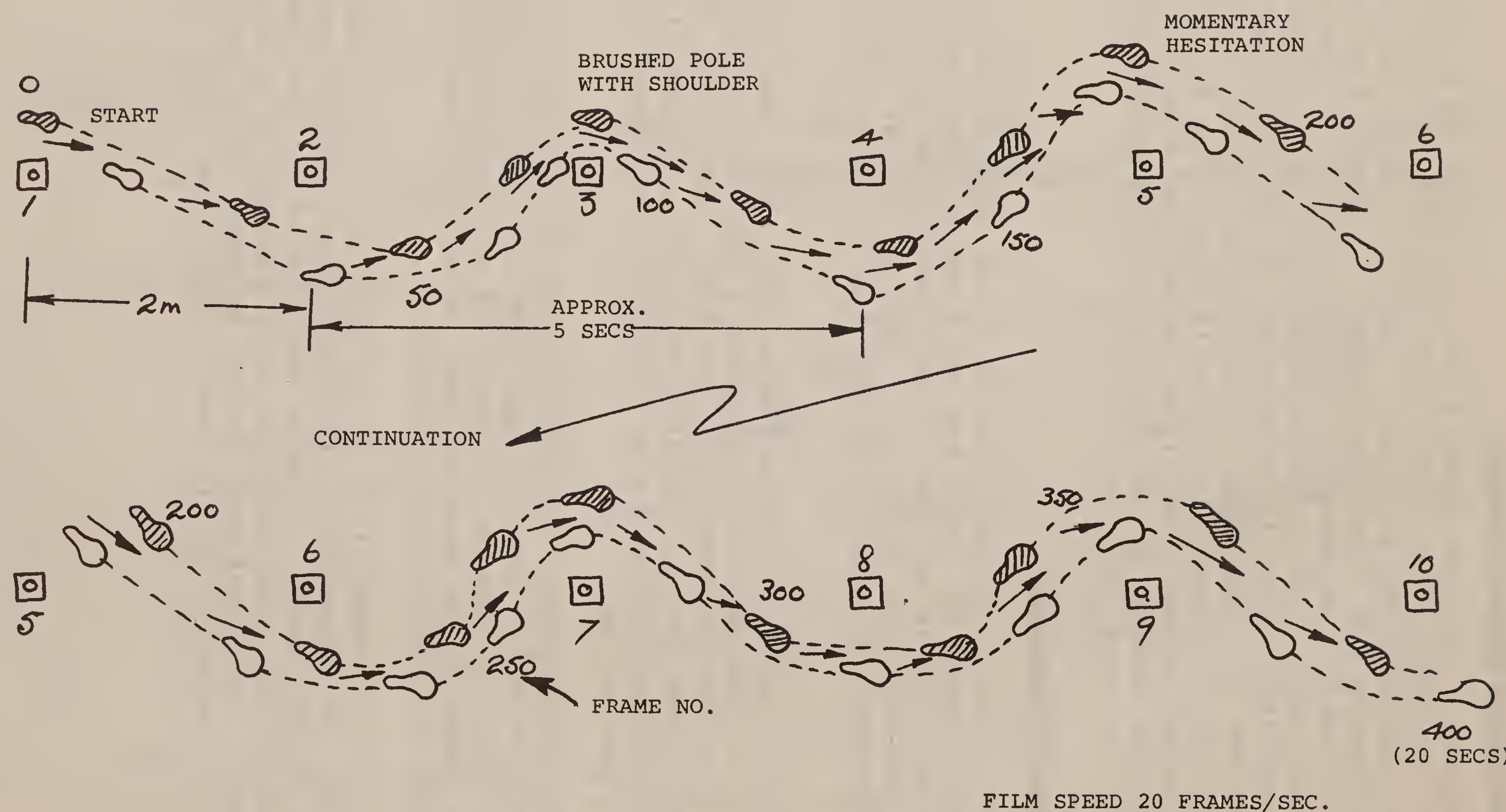
Both Subject 6 and Subject 7 are congenitally blind. The performance of 7 was not as good as that of subject 1 when walking in slalom; it was more like that of 2 or 3 (in the writer's opinion). This of course does not imply agreement or otherwise with the gradings of Subject 2 or 3.

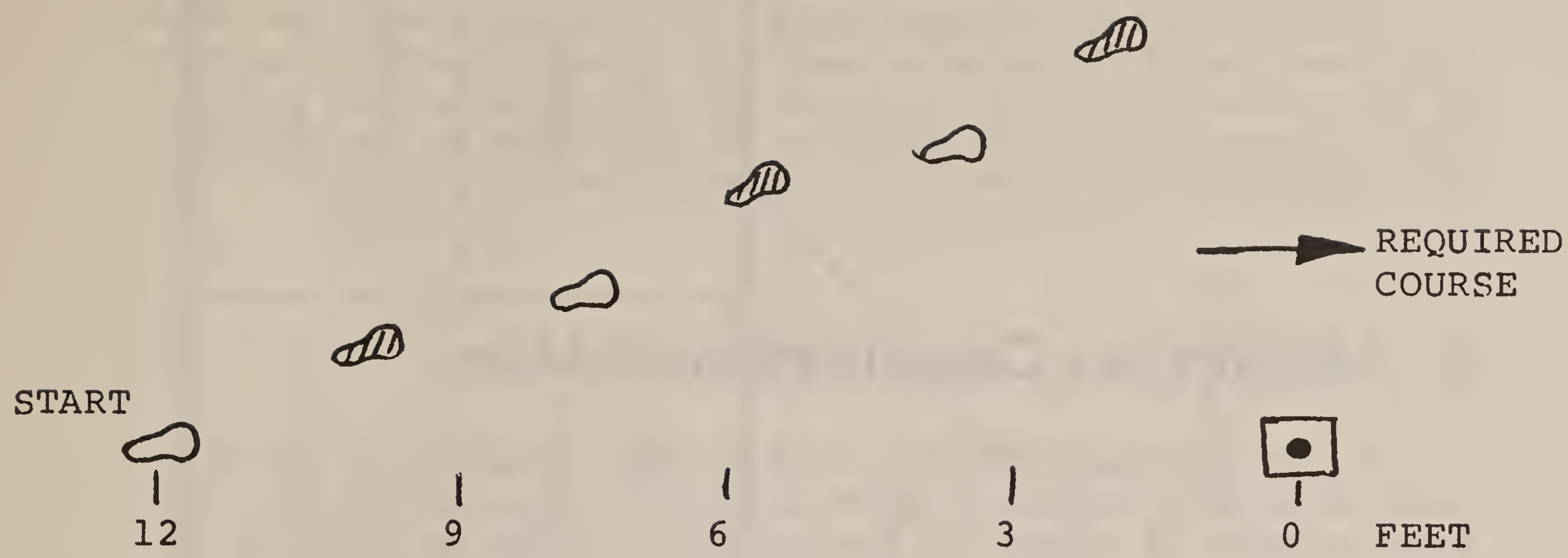
From Figures 5-8 it appears that some form of measurement is possible by attributing numbers to the walking pace, accuracy of executing the task, deviation of head movement from that of natural behavior, regularity of footsteps, hesitation, rate at which the course is established, and so on.

The grading must relate to some universally acceptable performance which can only be that of sighted people. To determine this, the performance of a selection of sighted people needs to be recorded and tolerances established for each variable to be measured.

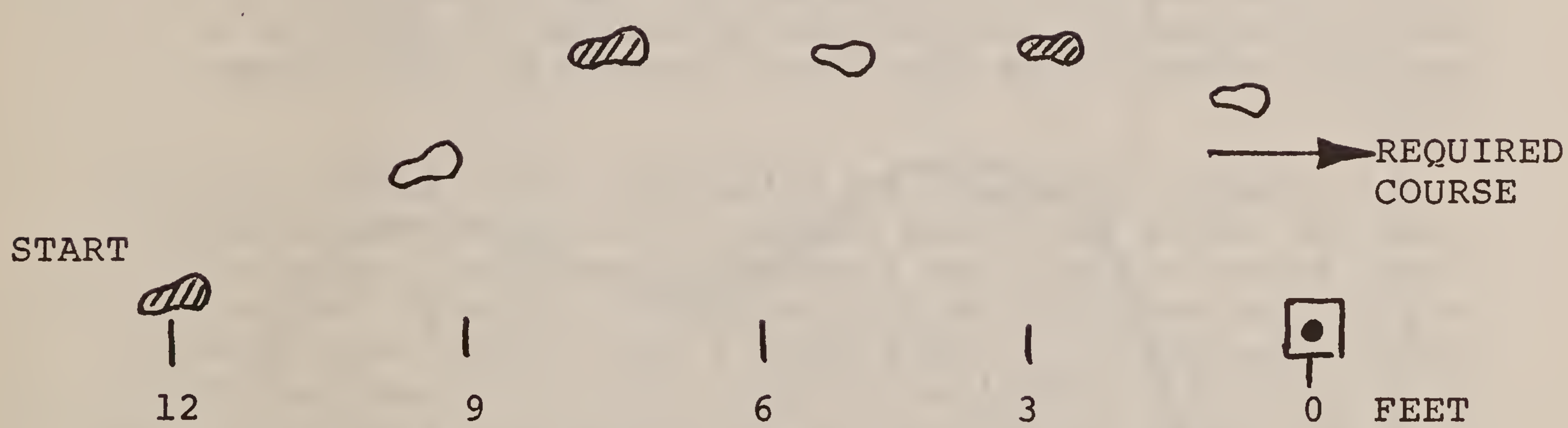
To obtain some guide as to what to expect from sighted subjects, an elementary experiment was carried out on a smooth, sandy beach. A pole was placed in the sand and a sighted subject was asked to walk past it at a distance of two feet. The first and second attempts were recorded from the footmarks in the sand; these are shown in Figure 9.

Figure 8. Blind Person Walking In Slalom Fashion Between Poles In A Straight Row.





ATTEMPT NO.1.



ATTEMPT NO.2.

Figure 9. Sighted Subject Walking Past Pole To Pass It At 2 Feet Distance.

Four poles were then placed in a square and the subject was asked to walk around the poles grasping each as it was passed. Initially, the distance from the poles was so great that the subject had to stop at each pole and reach out to grasp it, bending over a little.

5. Mobility as a Control System Problem

A model of man moving in his environment is illustrated in Figure 10; a more detailed diagram of his control system is shown in Figure 11. Although this is a very simple representation, it is much too complex to analyze; we cannot even describe the individual "black boxes" adequately. Hence, any approach to the problem via this route is, of necessity, going to be naive at present.

Held (1965) has shown, for example, that we cannot treat the spatial feedback link as consisting only of the visual or auditory pathways. Proprioceptive stimuli play a vital part in perceiving space. Experience teaching spatial perception to blind people confirms this; even the use of natural perception of sounds in space as a spatial control link has to be learned through locomotion.

A simple experiment to illustrate this point was carried out using two blind subjects who were both congenitally blind and who had therefore used their sense of hearing extensively to locate objects through the sounds these generated. A clock with a loud "tick" was mounted on a pole at a height of four or five feet and each subject was asked to walk up to the clock and grasp it. The task was found to be less easy than expected and both failed at the first attempt. Apparently they had not encountered such an unnatural situation and were unaware of their limited basic ability. Normally, they have other cues to supplement their hearing and a *sequence of events* always precedes grasping a clock in a home. These events were missing in the experiment. To learn the new percept of the clock, they once again had to practice walking up to it, controlling their movement and using the changing pattern of sound. This was found to carry

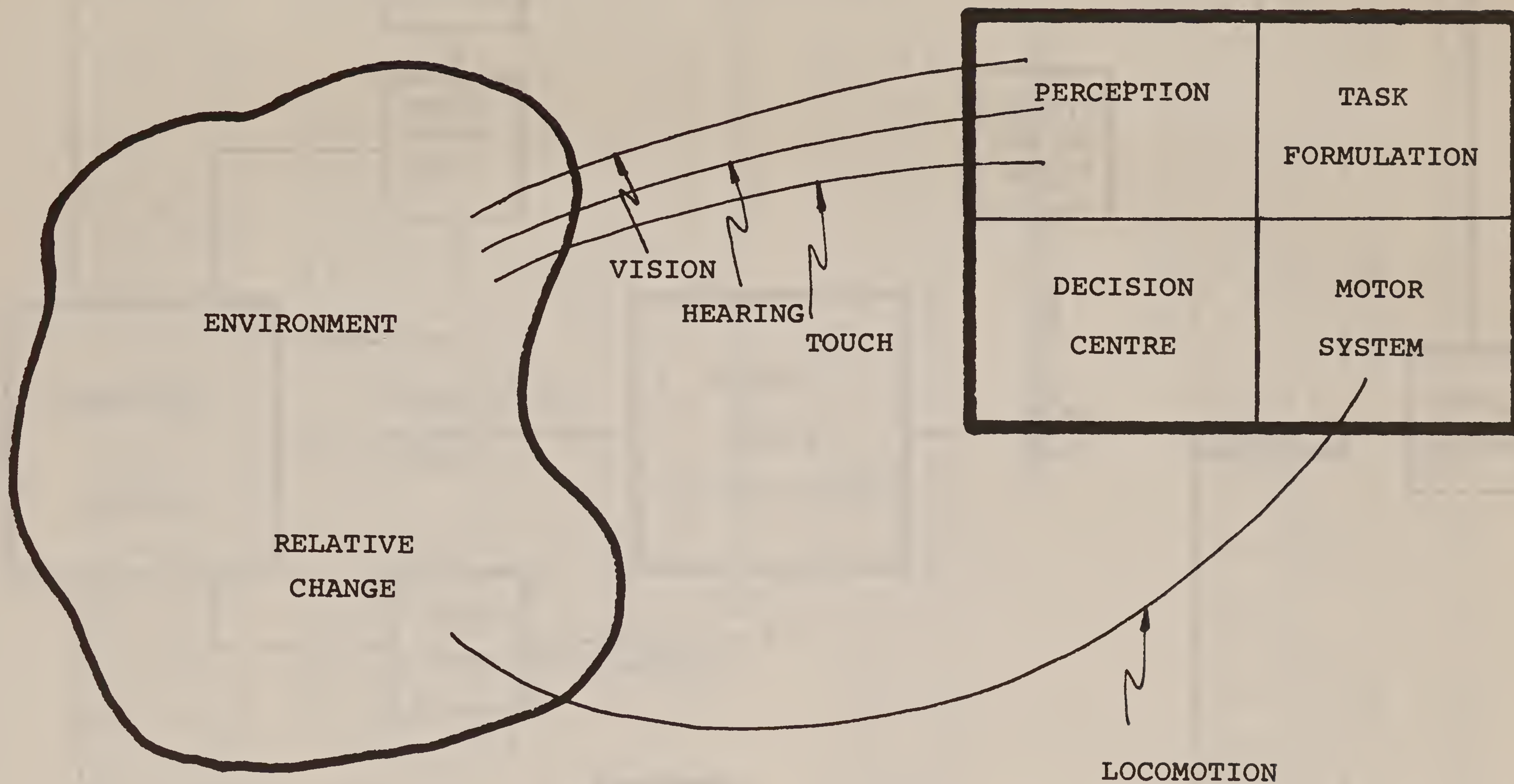
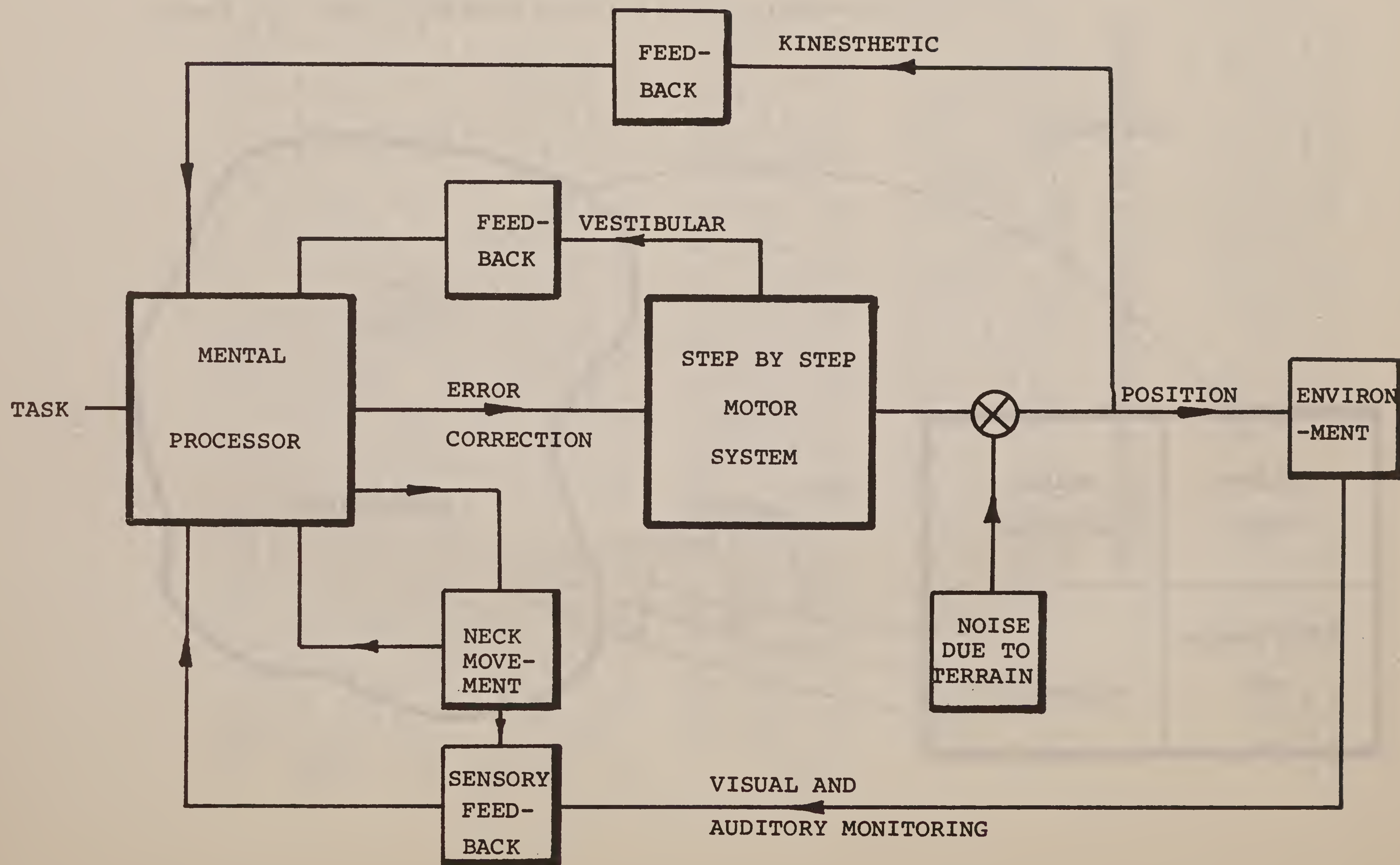


Figure 10. Man's Interaction With His Environment.

Figure 11. Control System For Human Locomotion.



inadequate information for the task, but their proprioceptive feedback assisted in making it possible.

While this experiment is trivial in terms of mobility, it emphasizes three important issues: a) The natural sense of hearing, acting as a control system feedback link, is not as good as we sometimes think it is. b) We have to spend some time learning to use our natural senses when presented with an entirely new control situation. c) Locomotion is necessary if we are to perceive new space in its true dimensions.

6. Basic Control Information

If we are to move about gracefully, we require information about the surrounding environment. The literature has not specified what this information is. Mobile robots have been constructed, but the essential difference here appears to be the use of conscious intelligence by man which is not available to the robot.

6.1 Distance OR Direction Information Only

Consider the simple task of walking past a pole from a distance of 12 feet to pass it at a distance of two feet. Subject 6 is shown doing this in Figure 6 (one leg of the square). The information required to do the task may be reduced to the simplest forms of either *Direction only* or *Distance only*. Figure 12 illustrates the way in which distance may be determined when only the direction of the pole is given. By taking one step in a specific direction relative to the pole, the rate at which the relative angle changes indicates the distance. This can be determined only roughly by the senses and careful thought has to be given to the mental calculation of the new course of action. Smooth control of the body in executing this task is not possible when the input is so limited.

Alternatively, one may consider the situation where only distance information is provided, as illustrated in Figure 13. If the fractional range change is registered, a series of widely spaced curves indicate the direction of the first step relative to that of the pole, but the distance to the pole needs to be known with some accuracy.

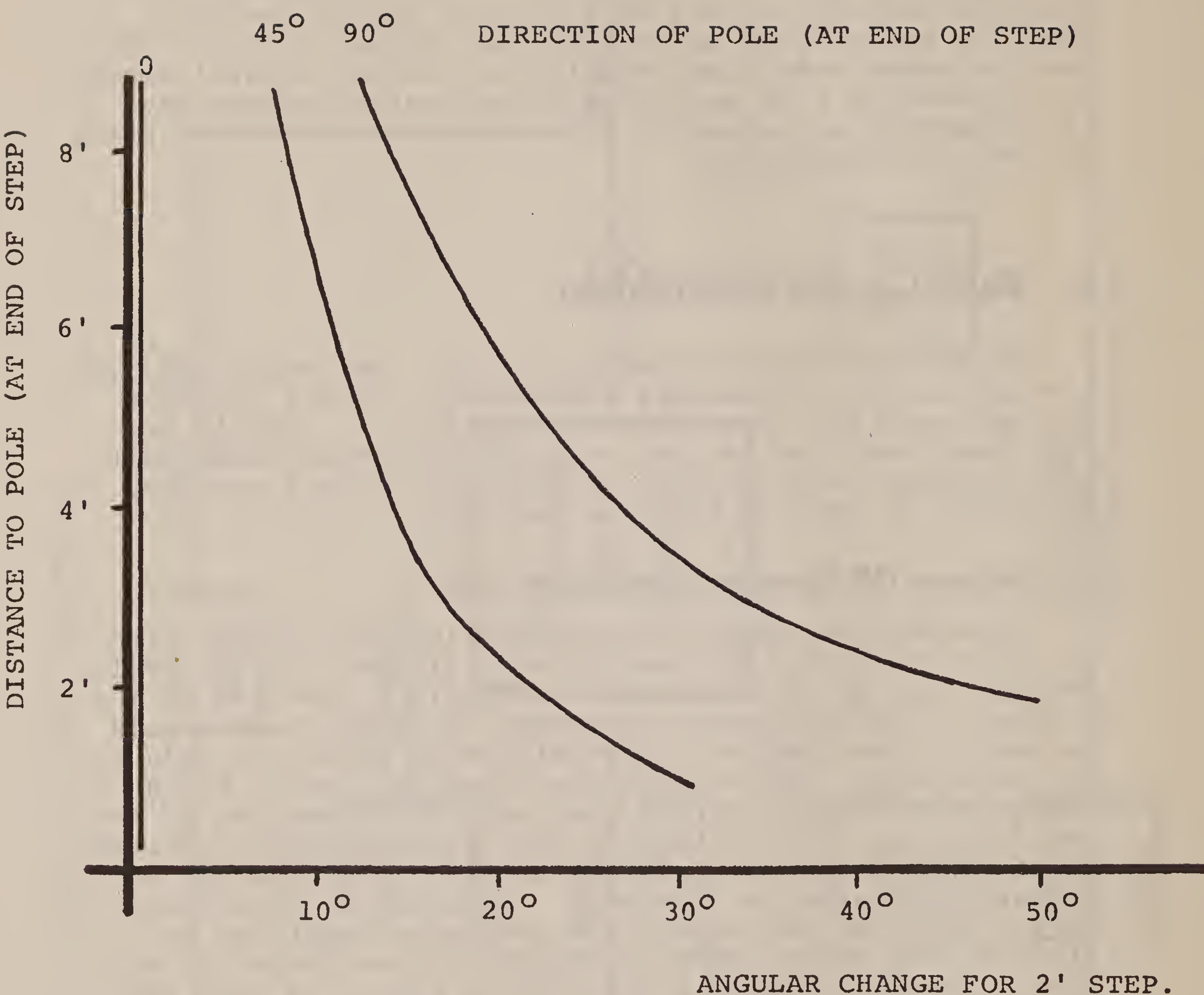


Figure 12. Direction Only Information.

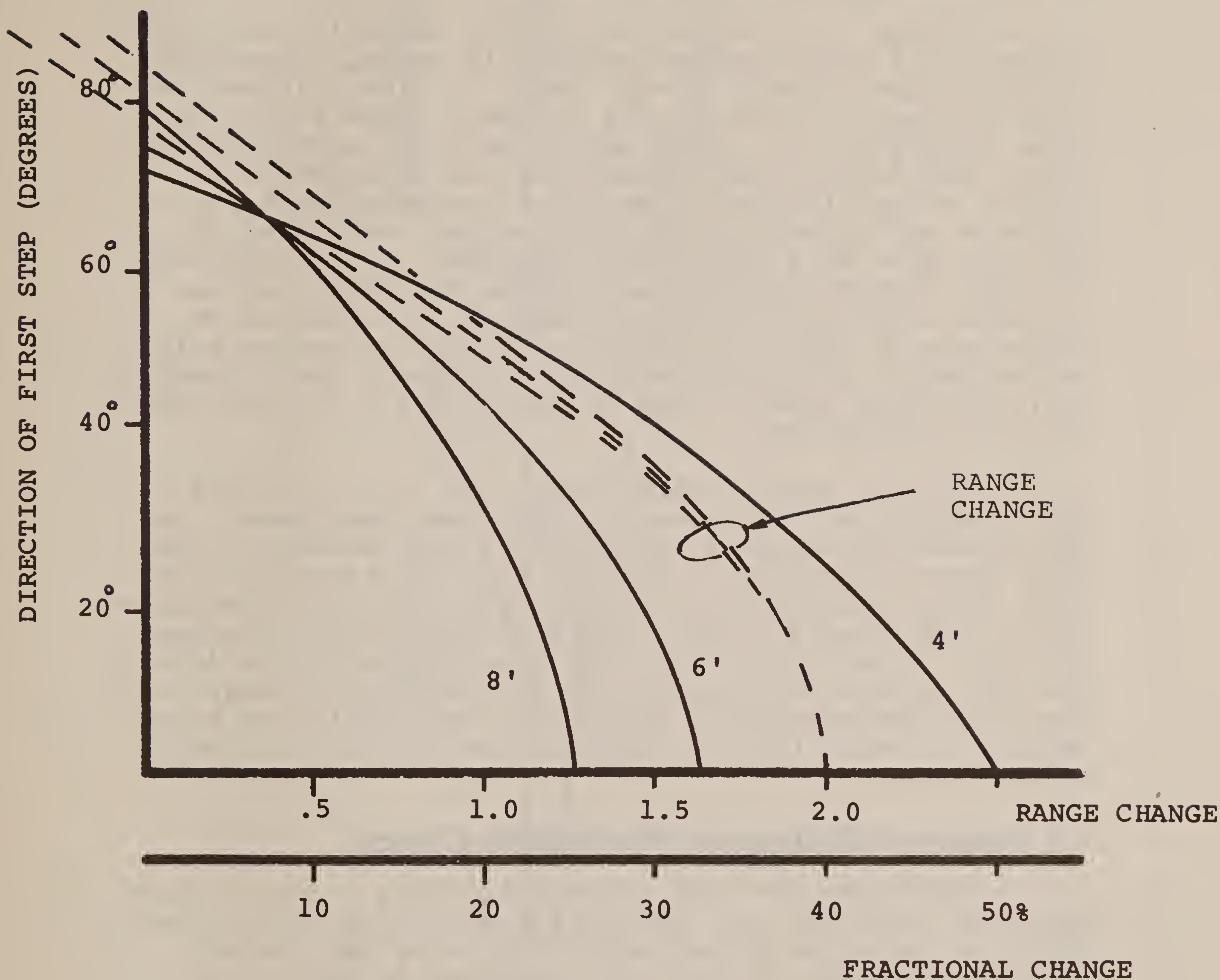


Figure 13. Distance Information Only.

If, instead, the actual distance change is registered, then the distance itself is less important in determining angle. Considerable thought must again be given to a strategy for completing the task, making a smooth, graceful motion impossible.

6.2 Distance AND Direction Information

In Figure 14, the task of passing the pole using both distance and direction information is shown, along with initial course errors of +10° and -5°. The information which becomes available, once movement takes place, is shown in Figure 15. These curves call for careful study before the form of the information can be understood. Imagine being blindfolded and then presented with this distance and direction information--the task being to pass the pole at a distance of two feet. It is not obvious what features of the information one would use and it would require some time to reach a decision before making use of them. If there is an initial course error, determination of action required to correct the situation as it develops after a step or two is not a trivial mathematical calculation.

It will be evident from Figure 15B that initially the direction of the course is of prime importance. As the terminal position is approached, the distance to the pole becomes paramount. Angular rate of change, on the other hand, appears to provide more sensitive information and by combining all the variables finer control becomes possible. Even so, it does not appear possible to determine the course and correct any errors using distance and direction information in their raw form within the three seconds it would take to complete the task at a normal walking pace.

6.3 Distance AND Direction With Multiple Objects

Consider now the task of walking along a row of poles as shown in Figure 16. Provided the ability to *discriminate* the two poles is adequate by knowing the distance and the direction of both, the task may be seen to be simpler. Figure 17 shows how the direction of two poles varies as the task is carried out. The more distant pole changes direction only slowly. Using this as a guide, the task becomes one of maintaining the direction of the farthest pole within a small arc slightly to the left of

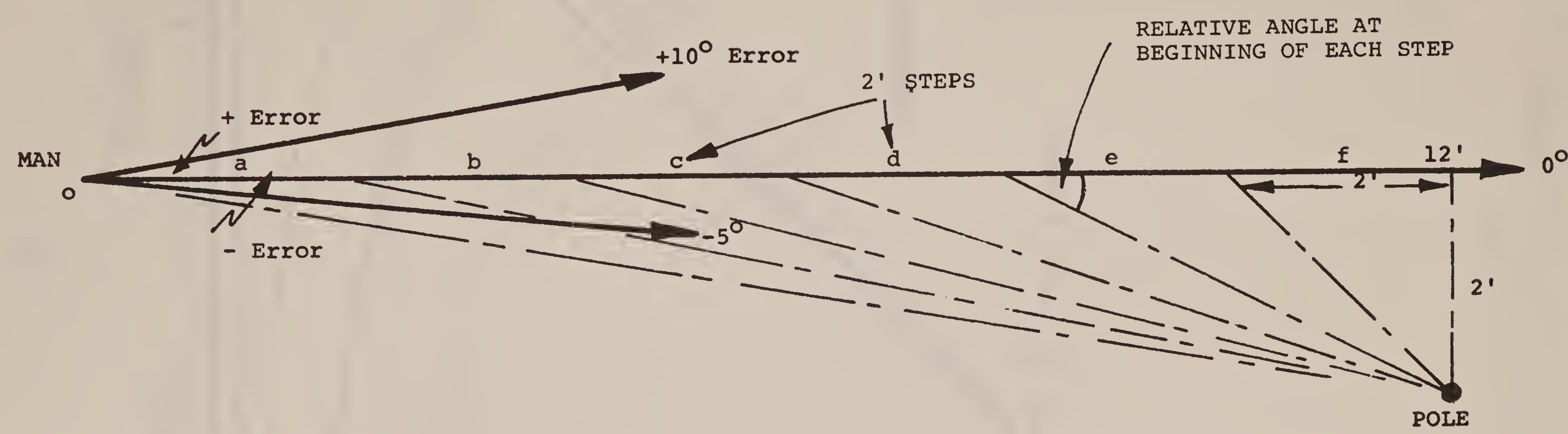


Figure 14. Walking Past Pole At Distance Of 2 Feet.

Figure 15A. Walking Past Pole Causing Distance And Direction To Pole To Change.

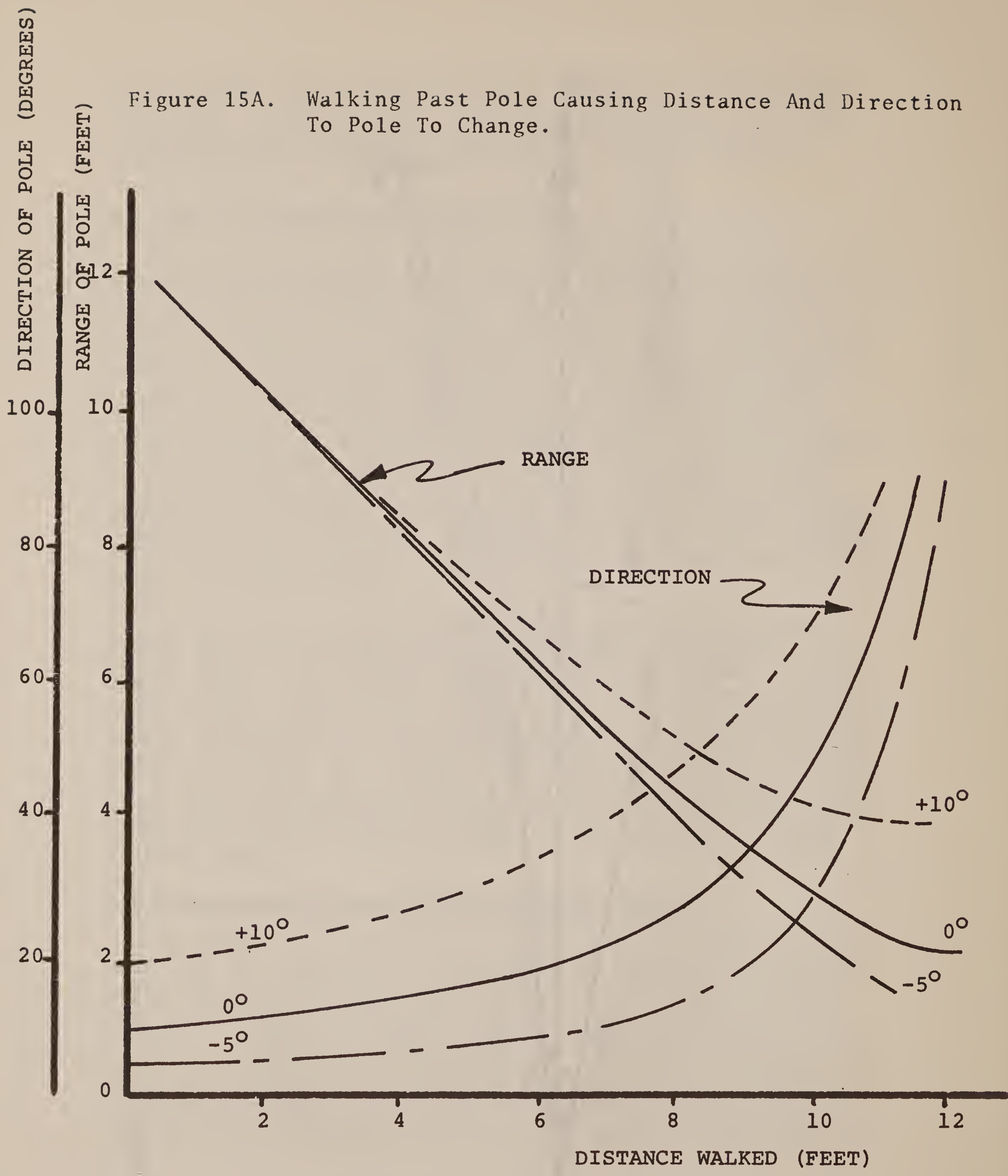
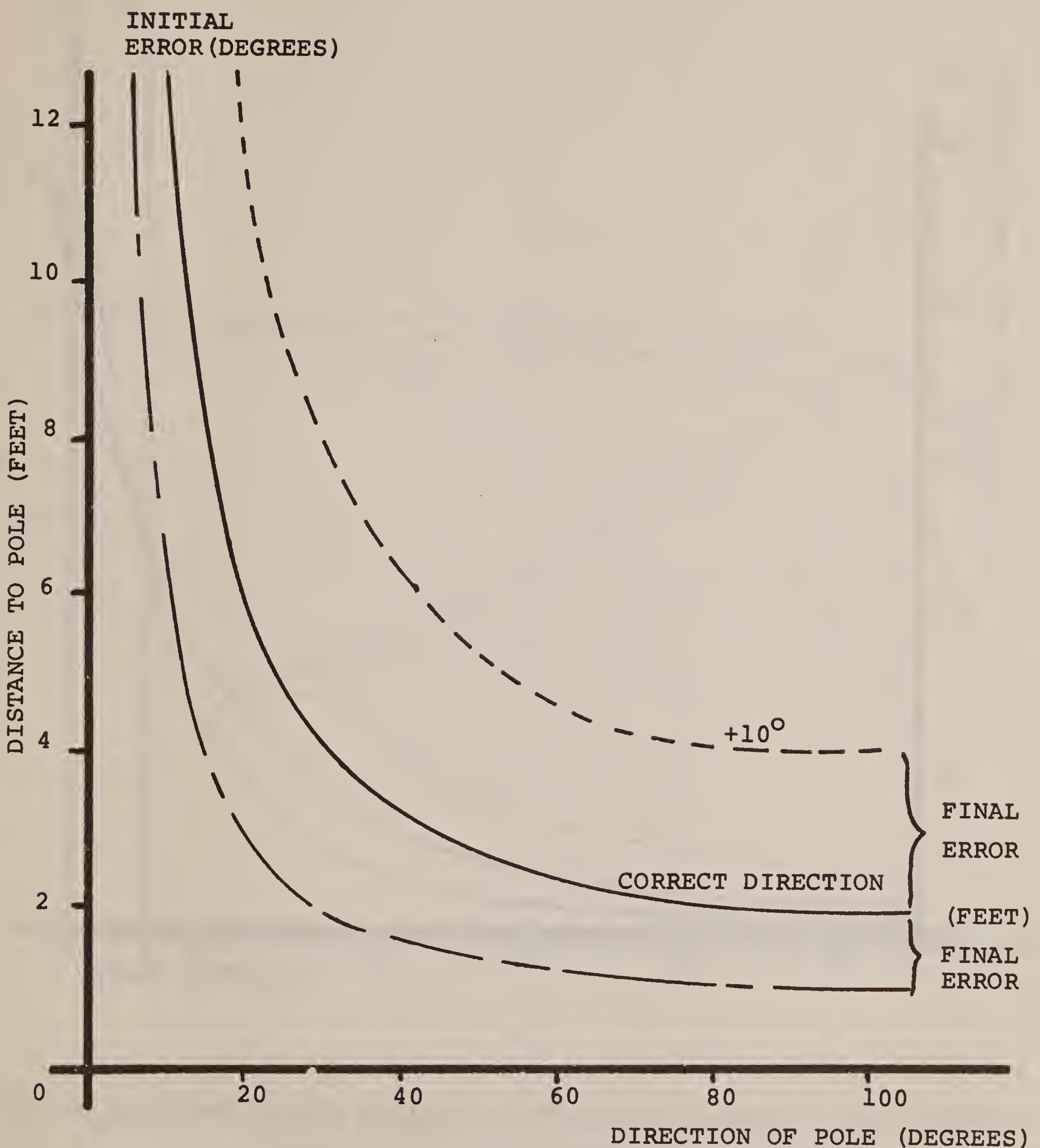


Figure 15B. Relative Change To Distance And Direction.



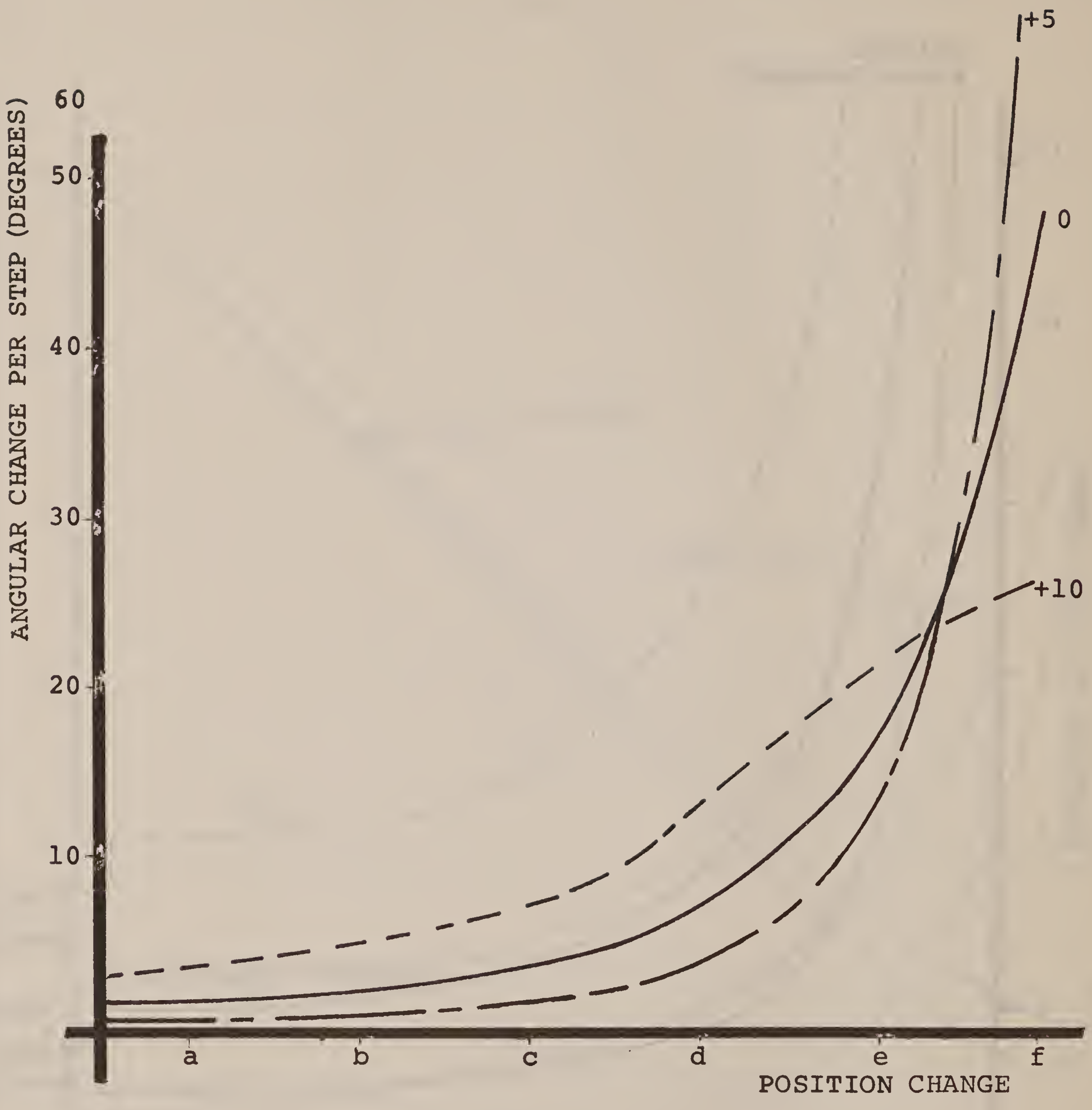


Figure 15C. Angular Change With Position Change Relative To Pole.

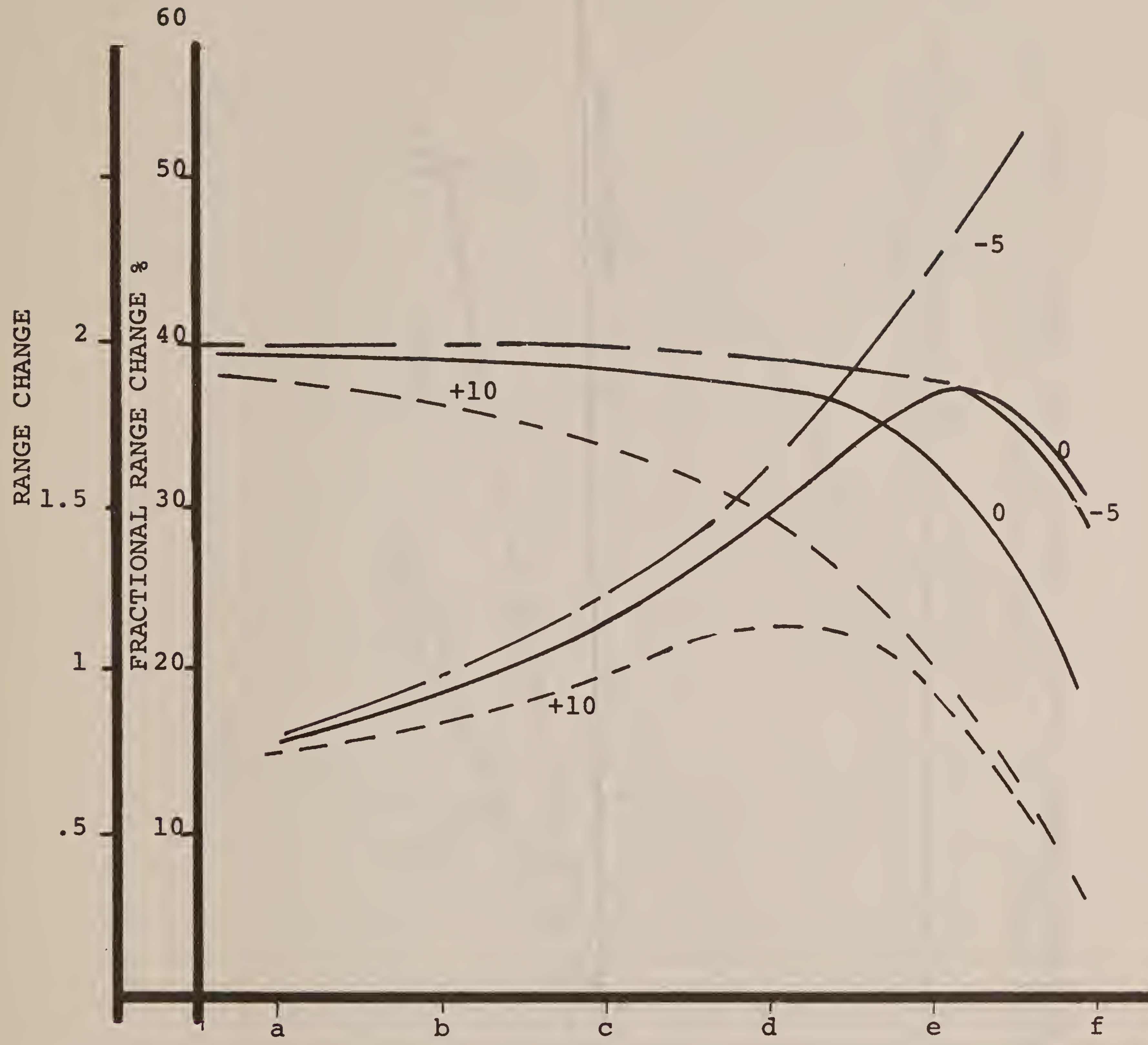
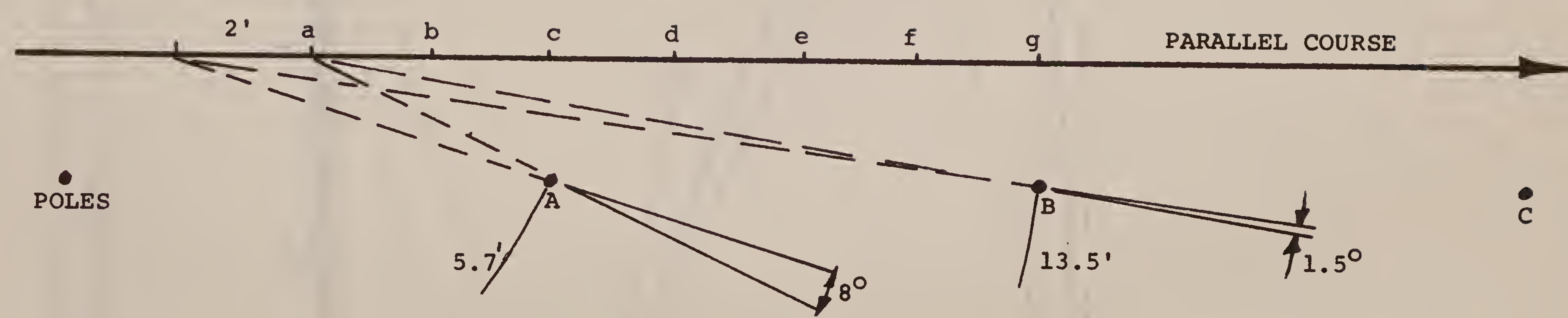


Figure 15D. Range Change And Fractional Range Change Plotted Against Position Change At Each Step.

Figure 16. Multiple Object Situation - Row Of Poles Spaced 8' Apart.



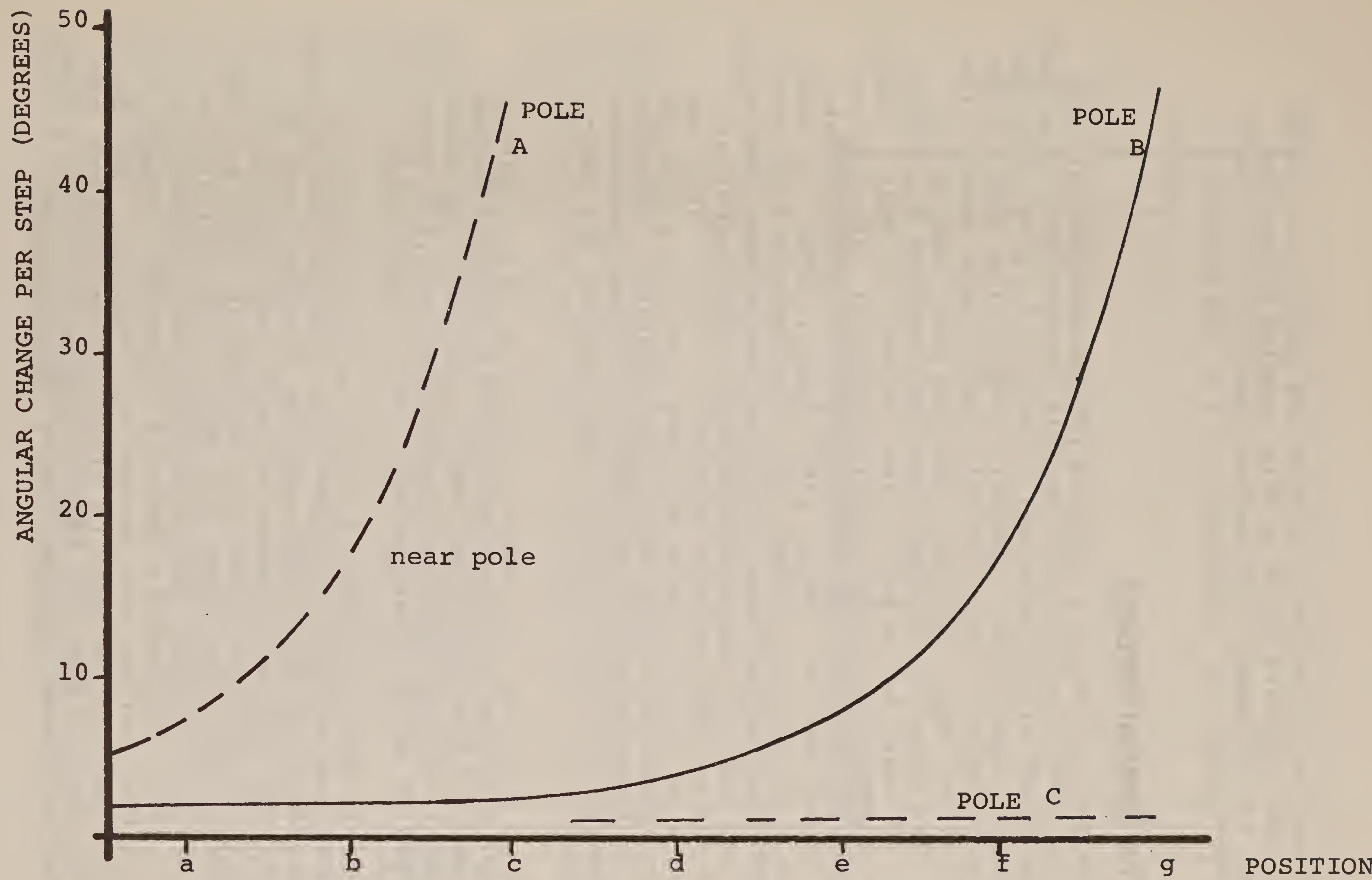


Figure 17. Angular Change In The Direction Of Poles Of Figure 8. As Person Walks Along The Row.

the direction of motion. Errors are easily corrected. Hence, what appears to be a more complex situation--because of increased information input--is in fact simpler *through the redundancy of the old information.*

7. The Spatial Percept

The pace at which a sighted person carries out the exercises described in Section 3 is so fast that conscious "computation" of distance and direction to give position is clearly impossible. However, because the task can be readily executed, even with relatively large errors, the "computation" must have been done at some time in the past. The question is when. We all perceive space but we had to learn to do so, to some extent at least. There may be elements of a percept already built into our central nervous system, but these apparently need stimulation through motion (Held, 1965; Bower, 1966). A newly presented situation at some later time merely activates the then-existing percept. This may be looked upon as the "read out" to the conscious level of the spatial memory and we then operate on what we "see." This can only be a pattern of space obtained from the processed sensory inputs of vision and proprioception. Calculation--or computation by the central nervous system--of the geometrical coordinates is not required for every "read out."

If an entirely new sensory situation were presented, however, a period of learning would be required before the task could be executed with confidence. The rate of learning is an important consideration, for it relates to the speed at which a new percept can be established.

Seventy-four blind people were recently placed in this position by being trained to use the new sensory aid. Both distance and direction cues are provided with the means to discriminate between at least two separate objects in the field of view. At the end of their period of training they were asked how long it was before they could use the distance and direction cues to *locate* objects. Their response is shown in Figure 18. Usually only one hour per day was devoted to training. The rate of acquisition of the cues to direction and distance can only be inferred from the data in Figures 19 and 20, showing that both were acquired almost simultaneously.

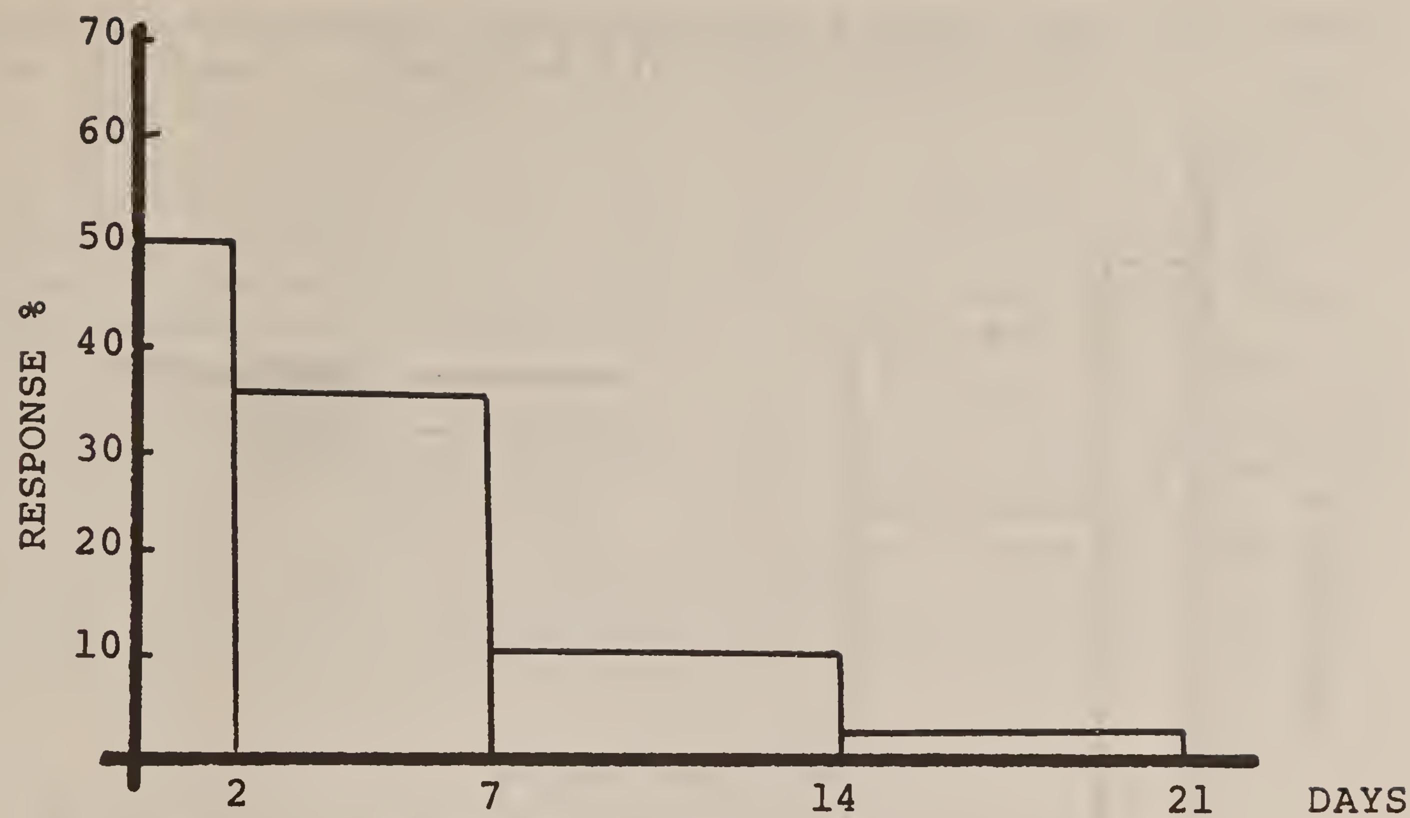


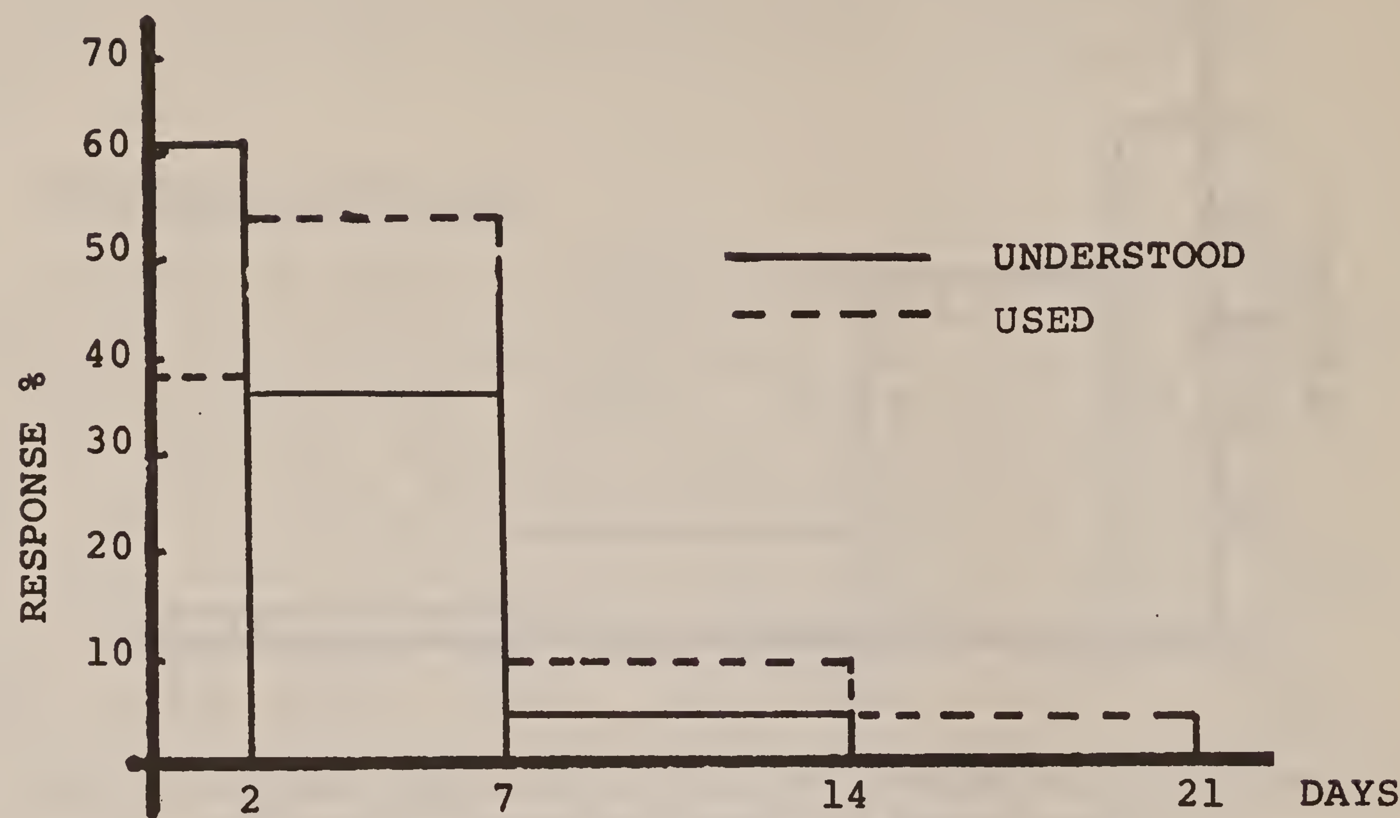
Figure 18. Day Before Pitch-Distance Cue And Left-Right Cue Could Be Used To Locate Objects.

Using the cues in a mobility task is not the same as *locating objects*, but extrapolating from detailed experience with a few subjects suggests that many of those in the evaluation group were able to do tasks (i) to (vi) in Section 3 within approximately ten hours of training.

When the distance and direction cues had been fully assimilated at the end of the training period of some 40 hours, the pole exercises could be done by at least some blind people at the same pace, and with comparable grace, as a sighted person (as with Subject 1 already discussed). Data on individuals in the evaluation group are not readily available, but many observations were made by the writer. There is a clear implication here that a *percept* had been formed which no longer required conscious computation of the spatial coordinates. In fact, the subjects must have been using new spatial patterns which could only have been in the form of changes in the sounds from their sensory aid, since this was the way the sensory aid worked.

It is, however, hypothesized that *any sensory aid to mobility must allow the formation of a spatial percept,*

Figure 19. Days Before Pitch-Distance Cue Was Understood And Could Be Used.



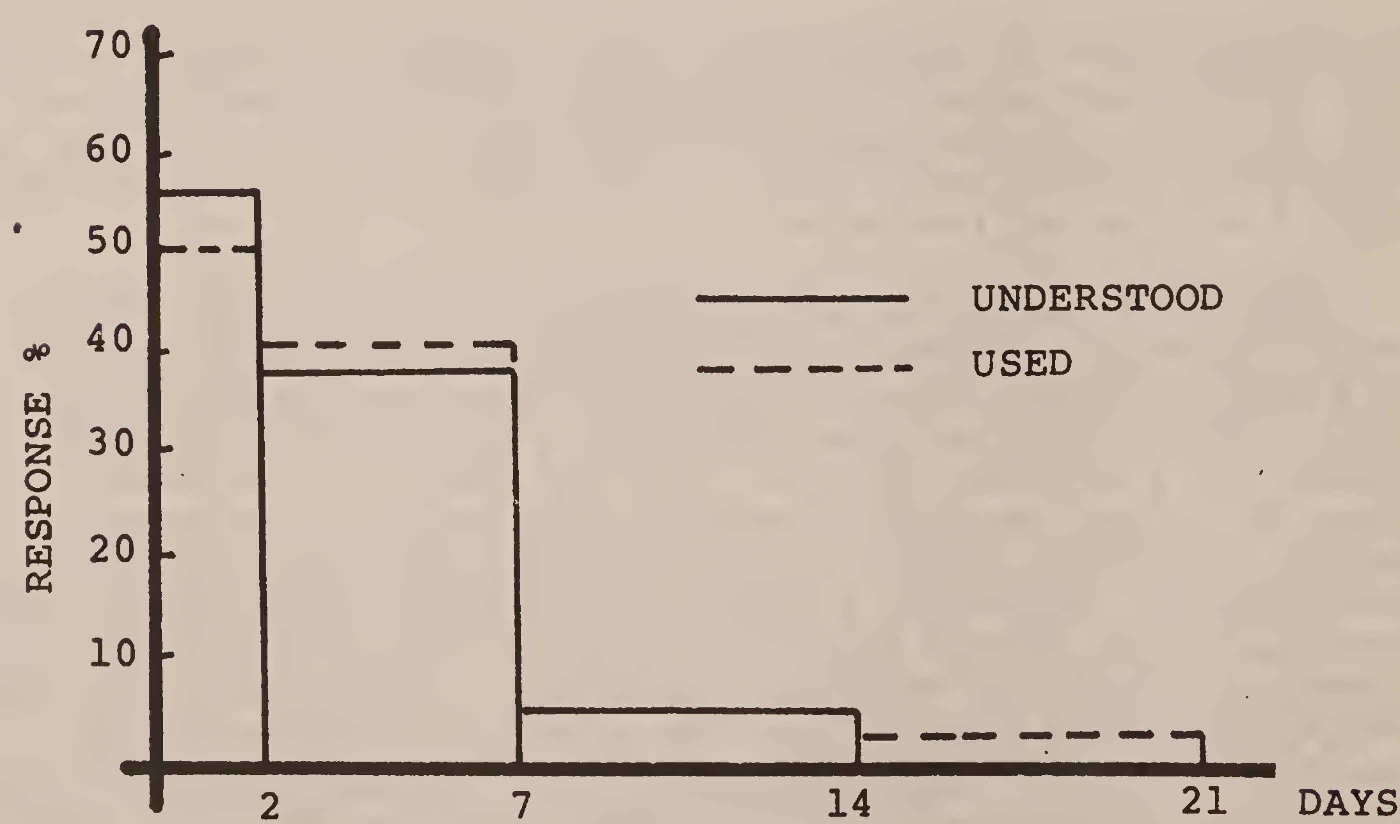


Figure 20. Days Before Left-Right Cue Was Understood And Could Be Used.

otherwise the skills described could not be demonstrated with the speed and grace of a sighted person. This must be a fundamental supposition. *To execute a mobility task, the input information to the spatial senses must stimulate a percept related to the task and the sensory inputs must be in the form that such a percept can be formed.* This becomes a prerequisite to mobility for blind persons and is not merely the outcome of the design of a specific device. It was only necessary to have a means for observing behavior from which a general conclusion could be deduced. Any device which is to be used for aiding mobility should meet this basic requirement. *The actual form of the sensory input and the initial response to it are not important, provided that the percept formed is quickly learned and can be used in conjunction with other percepts--or spatial inputs from other senses.*

8. The Formation of a Spatial Percept

The literature on human perception refers mainly to the act of perceiving rather than the object of perception--that of a *percept*. The writer has on the other hand referred to a percept because this is seen as the "display" of sensory information necessary for the act of perceiving. Such a distinction may be controversial, and possibly dangerous, but is is very convenient for the purpose of the present discussion.

Devices such as a radar, sonar, or television use displays which have a clear visual connotation, but a *sensory* system for perceiving space cannot have a display in the same sense if *neural processing* is an essential part of the overall system. The percept then becomes the display, which may well remain vague in the minds of many. It may be argued, of course, that a visual display such as used by a radar also requires perceptual processing before the picture on the screen has meaning; but what the operator sees does not *change* in form as he becomes experienced. This is not unlike medical diagnosis, using photographs of sonargrams. We all see the same thing but only a medical specialist "perceives" the abnormality and can diagnose it. He is required to interpret the picture and the mental process necessary in making a decision may be considerable. The two processes are nevertheless quite different.

When considering a new sensory system, rather than enhancing an existing one, we also have to consider the process by which the percept is formed, such that the act of perceiving becomes possible.

The sensory aid, used as an example in this paper, produces sounds never before heard in this way. They are listened to binaurally. On first hearing them from, say, a tape recording, they have no meaning; without instructions it would probably be impossible to decode the information. The situation is different when actually using the aid, which is head-mounted. Head movement changes the sounds in a well-defined and repeatable way. The motion of the body is immediately sensed from the change in sound and the rate of movement adds a further change to the basic change produced by movement from one position to another. A very complex pattern of sound is thus produced and this can be learned only by relating it to body motion monitored by proprioceptive and cutaneous feedback as objects are negotiated or touched.

Gradually the perception of motion through proprioceptive links coincides with the perception of sound change due to the motion. The position may be reached, for example, when the sound of a rope flapping against a metal flagpole, the sound produced by the device when the echo is received, and the change in both sounds as the observer moves, coincide in such a way to give the observer a percept of a single flagpole at, say, six feet and at the one-o'clock position relative to the direction of motion.

8.1 A Perceptual Model

During the evaluation of the sensory aid, blind subjects were taught to use the device in a mobility setting first by learning the pole exercises described above. The technique used by the teachers was to "talk" their students through the exercises, as is their normal practice in teaching the long cane (Mobility Workshop, 1961). All blind people taught in this way were initially very hesitant and required patient observation and coercion until, through exploratory trial and error, they acquired an ability to control their movements in the artificial situation.

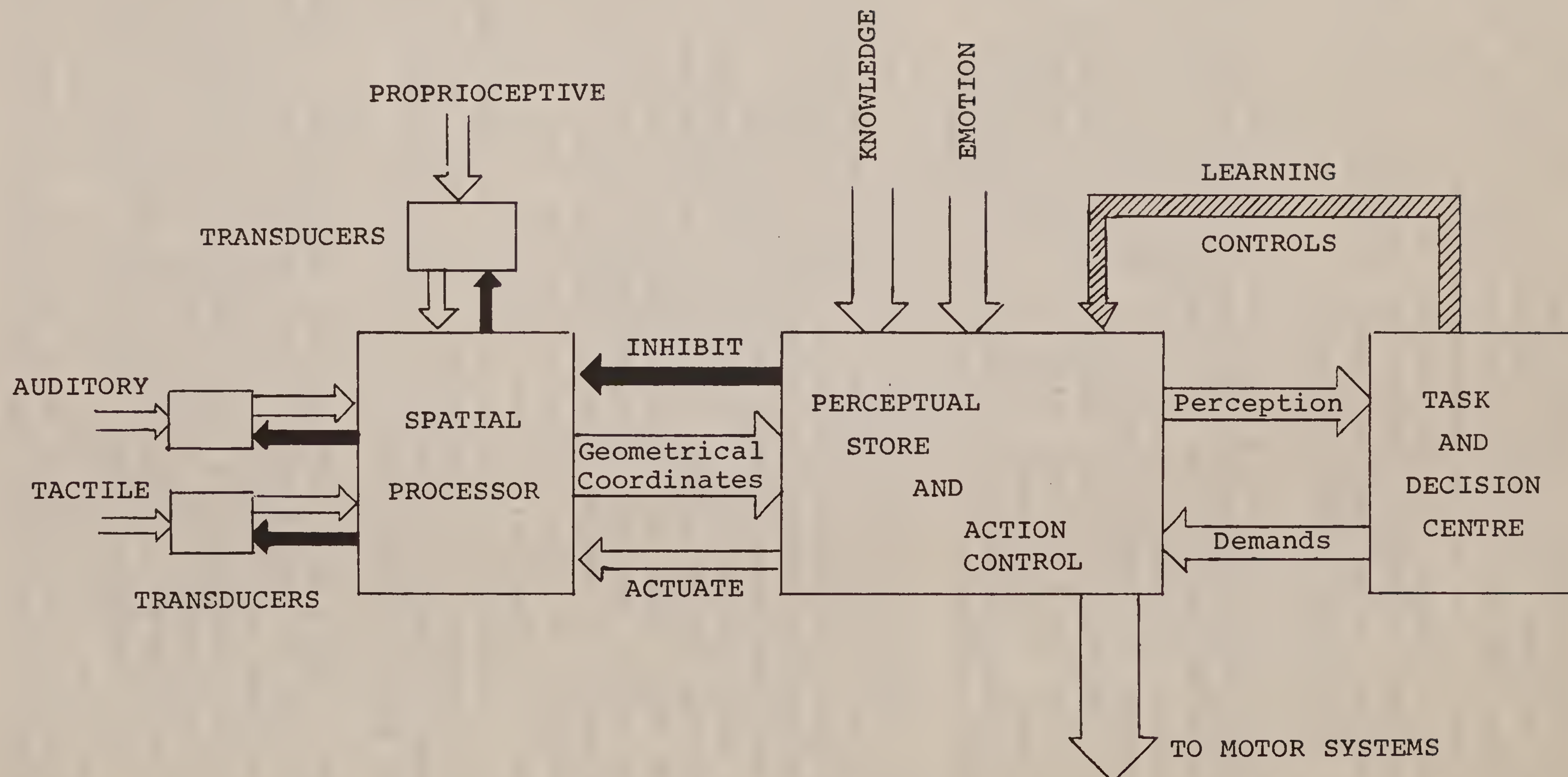
Each person was in his own way trying to construct a percept of the situation through the only sensory cues available--those of distance and direction as discussed in Section 6.2--*before* making a move. Each cautious step produced a change in the sounds of the device, demanding considerable thought before the change had meaning. Learning was slow and may have remained inadequate in a number of subjects so trained.

A few subjects were specially taught by first physically guiding them through the exercises, thus providing maximum reinforcement. At the same time, it was possible to illustrate to them the effects of errors in their movement. Acquisition of the "technique" for executing the tasks was quickly learned by this method and with much less hesitation on the part of the student when attempting the exercise alone. It appears that in this way one learns a *pattern of sound change*, one which is difficult to generate through hesitant self-exploratory movement.

All subjects must have attempted to relate the initial sensations from the device to some prior experience, although none could be found to fit the new situation. When commencing the exercises each subject hears a tone which seems to come from somewhere in the head. This moves about as the head is turned. Forward or backward movement changes the pitch of the tone. The thoughts of each subject at this time are indeterminate. At the end of a relatively short period of learning, the changing tone becomes a pole which is being approached as the pitch gets lower. The thoughts of the subjects become more determinate and what each person perceives begins to fit into a common pattern. Gradually subjects will say that they find the sounds external to themselves, but one cannot be sure what this means; only the verbal responses become more uniform for any given situation.

The process may perhaps be modeled as shown in Figure 21. It is suggested that signals from all the spatial sense organs are handled in a *spatial processer*, which arranges for the spatial coordinates, in the form of coded neural impulses, from one sensory input to coincide in some way with those from other inputs related to the same task. For example, when the blind people first attempted to grasp the ticking clock fastened to the pole, the auditory coordinates, which were poorly defined, did not coincide with the familiar and well-defined kinesthetic

Figure 21. Brain Functions For Self Locomotion.



coordinates but, through learning, one supplemented the other and the ability to do the task improved. The Binaural Sensory Aid, on the other hand, provides well defined distance information together with direction information which may be as good as unaided natural hearing, and learning to grasp the pole is found to be easier. Final accuracy is better and the task is done with greater confidence due to the additional distance information.

Once spatial coordinates have been assigned and the position estimated, the information in the new form may then be fed to a *perceptual store*. Here the incoming information may be correlated with prior experience of all kinds related to the task. If correlation with existing percepts is poor, the spatial processer may reassign modified coordinates until either the correlation is good, or the new information is given its own place in the perceptual store. Old spatial percepts which are no longer adequate may be erased to make way for the more recent and accurate incoming "data." This kind of process must be an on-going one as learning continues, until all inputs stimulate only one percept--that of the space being sensed. Both the auditory and the proprioceptive inputs may then be said to be matched, and coordinated motion can be achieved.

Imagine standing on a New Zealand beach and near one's feet is heard a strange rattling sound; the reaction would be to look and explore. If, however, the ground underfoot were known to be the Arizona desert, the reaction would be very different; it would be unnecessary to see the distinctive marking on the back of the coiled snake before taking action. The rattlesnake would have stimulated an adequate percept by its sound radiation which correlated with prior inputs to the senses.

The conscious-level activity normally has ready access to the perceptual store and can use the *images* this provides to formulate actions and make decisions. A task and decision center must then exist in the mind which can perceive the images from the perceptual store. Without it, actions would be uncoordinated and observers would see the behavior of an individual as being exceptional (handicapped, retarded, etc.).

9. The Relevance of a Percept to Mobility

Mobility in our everyday environment, as we see it visually, is a complex process. Since we act without conscious thought in many mobility situations, we are not normally aware of what information we are using. However, there appear to be three skills which we can consider as being basic to the process: i) Walk parallel to a boundary of a path. ii) Walk perpendicular to an object without colliding with it. iii) Walk past an object in the travel path and re-establish the original course.

9.1 Walk Parallel

To be able to walk parallel to a boundary such as that shown in Figure 22, it is first necessary that this be perceived as having *direction* and the distance to its nearest point must be frequently monitored. This requires a spatial *pattern* corresponding to the physical world and the sensory input must be capable of providing such a percept. There are a number of ways in which the direction of a boundary may be perceived non-visually. Scanning an ultrasonic torch by hand has been shown to be one method (Elliott, 1968); the long cane can be used to trace the boundary, with the direction determined by the kinesthetic response (Long Cane Conference, 1972); the Binaural Sensory Aid provides another method (Airasian, 1973). It has been proposed to stimulate the visual cortex as a further method (Stirling, et al., 1971). There must be others. All require an ability on the part of the user to perceive and give attention to *more than one point in space* since a single point has no direction.

9.2 Walk Perpendicular to an Object

It is important that one can walk up to an object when mobile. While there may be no necessity to touch it, we do often approach specific places: a pedestrian control position, bus stop, letter-box, pedestrian subway, shop doorway, etc. What we are doing is directing our bodies perpendicular to a specific place, rather than an object, and recognition of the place is first necessary. The percept of the place or object must be adequate for this, such as in Figure 23.

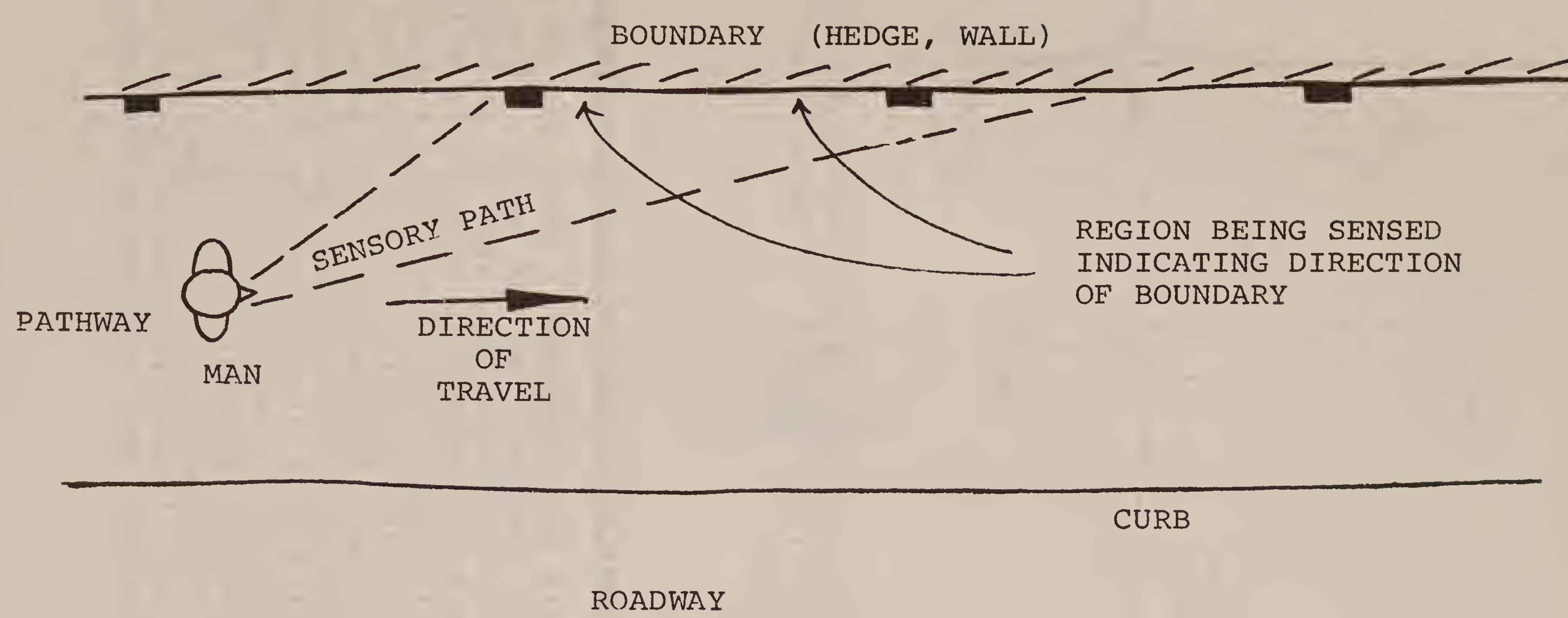


Figure 22. Walking Parallel To Boundary (Shoreline)
Using Region Being Sensed To Indicate Direction.

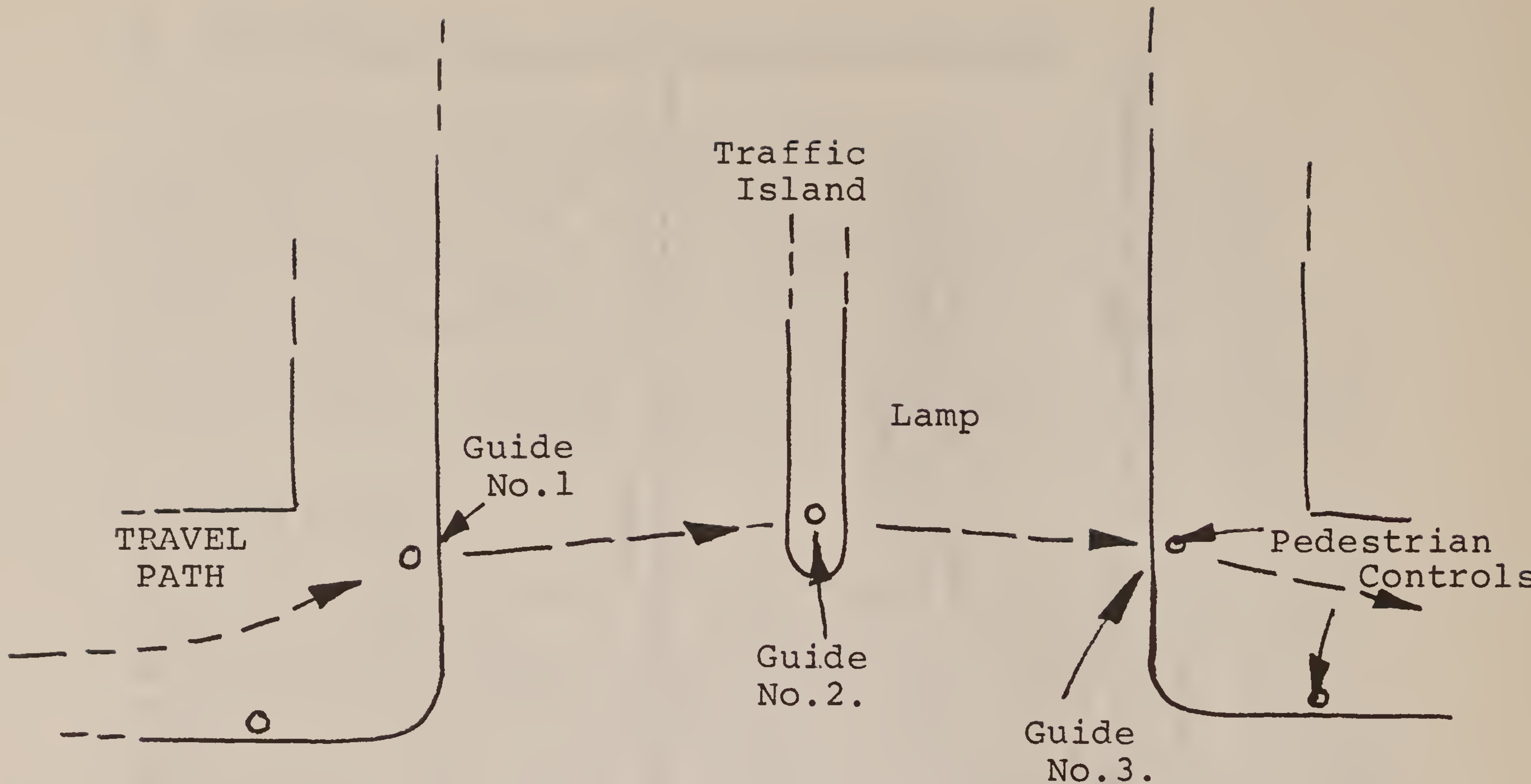


Figure 23. Crossing A Street Using Pedestrian Controls And Traffic Island As "Perpendicular" Guides And Points Of Safety.

9.3 Walk Past an Object (Combination of Parallel and Perpendicular)

We commonly walk past objects. These may be obstacles in our path or landmarks on our route. They may themselves be capable of movement, such as pedestrians. After passing them it is necessary that we be able to resume our original course. This requires a percept of the object in some spatial position, its relative movement, and any additional information which gives the required course. This would usually be the boundary of the travel path, in which case discrimination between the spatial position of the object and that of the boundary is necessary. Some distant landmark which can be perceived (a traffic intersection making a noise) may serve the same purpose, but only temporarily since "parallel travel" relative to the boundary must eventually dominate (see Figure 24).

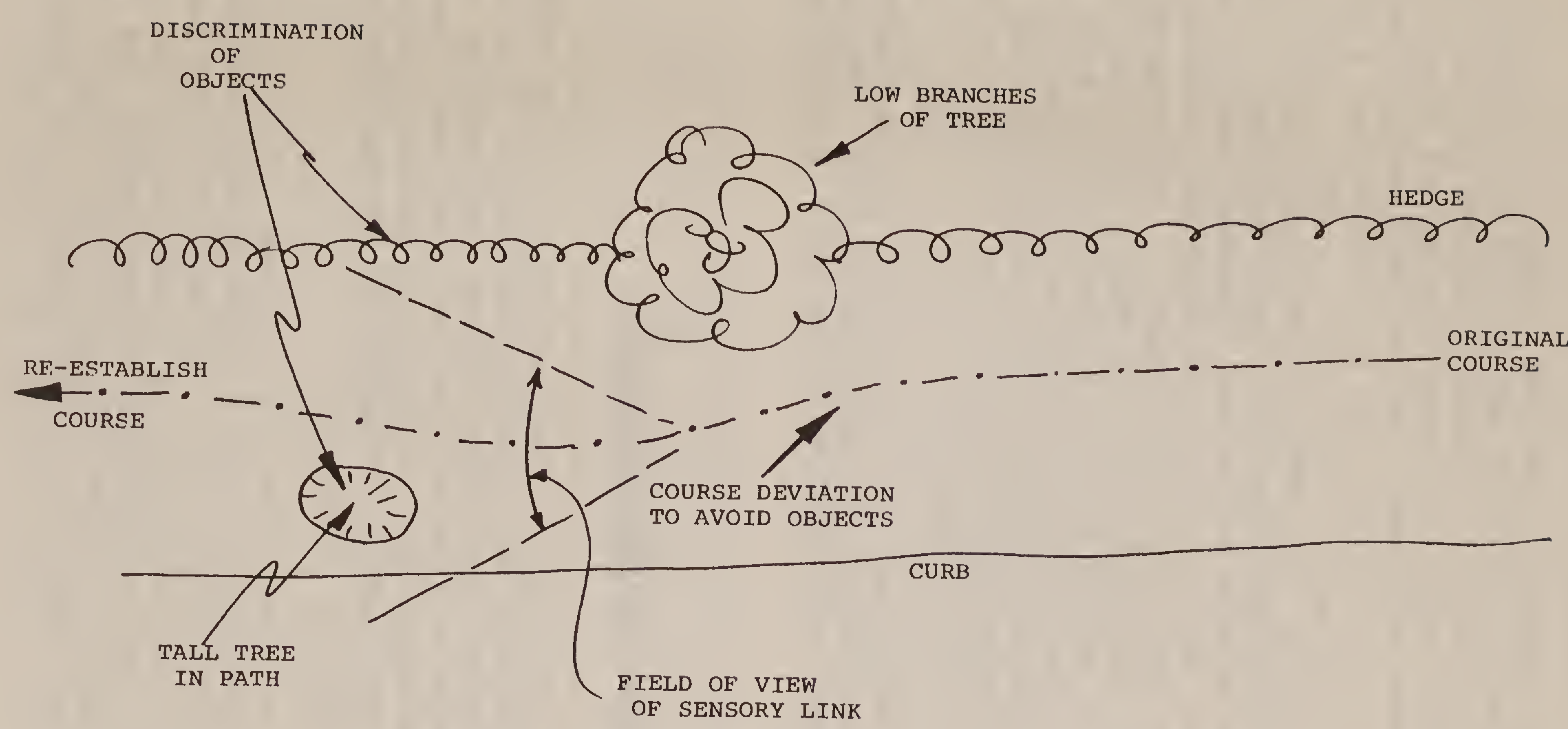


Figure 24. Avoidance Of Objects In Travel Path.

9.4 Relevance of Pole Exercises

The exercises listed in Section 3 enable an individual to develop both a percept and the skills required to negotiate situations of a similar nature in the real environment. While there are subskills other than those described which are required, such as following a wall or a hedge, those who learned the pole exercises found they were highly relevant to mobility. During early training 86 percent of the subjects realized their relevance and after training this rose to 97 percent. The *patterns* of sound change which were learned during the training exercises were encountered frequently during walks in suburban and city environments. For example, when walking past shop windows, one hears the same or a similar pattern of sounds as heard when walking past a row of poles. If the pathway is narrow and lined with parking meters, the sound pattern is not unlike that which may be heard when walking between two rows of poles when the poles are similarly spaced.

The pole exercises were in fact the training medium for the three basic mobility skills discussed. Other training situations can readily be devised to help improve the skills.

10. A Language of the Environment

The three basic skills essential to mobility would be of little value if they were not transferable to an infinity of situations. The shop windows and parking meters can be related to the initial training exercises only, because the means for recognizing the similarity is made possible through the "language" of the environment and the percept it produces.

Consider for a moment the part played by our visual senses while we are mobile. It is immediately evident that a very significant part of the total information input is redundant. We know that at times our visual input can be inadequate for recognizing objects which are viewed from a strange aspect, as for instance with "puzzle" photographs. Under these special circumstances, the details

of the picture may not be important; a clue to the object is often sufficient to stimulate the required percept and much less detail would then be adequate. In other words, without the *text*, the *words* may be meaningless, but because of familiarity with the situation, it is not always necessary to be given the whole text. A crucial word may be all that is necessary in order to "recall" the required percept.

If, however, a totally new text were to be presented, the word-by-word detail in grammatical form would be necessary and the *language* would have to be understood. Walking from place to place may not, in fact, be unlike writing an essay. In parts we will give special attention to the syntax and semantic links in the sentences in order to create the wanted environment. To the visual being, this may sound unrealistic; to the blind person, using some sensory aid, the creative problem is real. To walk from the office to a restaurant the first time demands an ability to use the language of the environment and an adequate percept. This makes possible the formation of the correct sentences to construct the text, which should then read all the way to the desired goal. A minimal skeleton of the route required for understanding must be provided.

The *grammar* of the language is the set of rules which relate individual terms of the sentences and text. Once understood, transfer of grammatical structure from one situation to another becomes possible. For example, lamp posts are mounted on the roadside of the pathway, except when the road is narrow, they may be mounted on the main boundary of the whole roadway. It would be "ungrammatical" to see a lamp post in the middle of the pathway, except if this were a pedestrian mall, say. There are many simple, as well as complex, examples of the grammatical structure of the environment in which we live. As it is with verbal language, the grammar is man-made. Nature may be thought to have no grammar either in sound or environment, yet observation of the animal world leads us to believe it is just as meaningful there as it is to man in his own city. But it has to be learned. We do, however, speak and walk about equally freely when all our faculties are available. To put the speech into writing is a more difficult matter. The skill of physically writing words has to be learned and the structure of the sentences carefully studied. To walk about blind with a new sensory input, the skill of

maneuvering in the environment has to be learned and the way in which the environment is structured has to be carefully studied. Mobility then becomes like writing a book rather than reading one--which may be the initial analogy drawn--when first attempting new terrain. Once traveled, the task is that of "reading," but instead of following "page-by-page," one is constantly having to decide which of several pages is the right one to choose.

The visual traveler has many cues to use when choosing the correct "passage": maps, signs, building structures, etc. The blind person lacks the long-range visual aids, but when traveling blind we discover certain important factors relating to blind mobility. The sounds generated by the environment have more meaning than we may at first think. The noise of traffic tells us the direction of the roadway, the width of the road, the number of lanes in use, the position of the intersections, whether or not these are controlled by lights, the density of the traffic, etc. We may even be able to position ourselves quite accurately on a cognitive map if an intersection were unambiguously described by its sounds.

If the sounds by themselves do not give us all the information contained in the environmental "text" which we need to use, some additional parts of the "text" must be "read." *A-priori* information aids greatly in interpreting the immediate surroundings, but to move about with grace there is a demand for detail which can be supplied only through a sensory aid. This provides the sentence construction which adds sense to the whole text. To be useful, the aid must be capable of conveying at least some grammar.

Examples of the failure of a blind person to use the environmental grammar are shown in Figures 25 and 26. In the first example a blind person traveling through a university campus along the pathways as shown, stopped correctly at the curb. He passed between the parked cars and crossed the road perpendicularly. Before touching a car on the other side of the road he stopped and turned left correctly. Instead of using the grammatical rules, however, and passing behind the car to the footpath, he continued out into the intersection where he became disoriented and sought assistance.

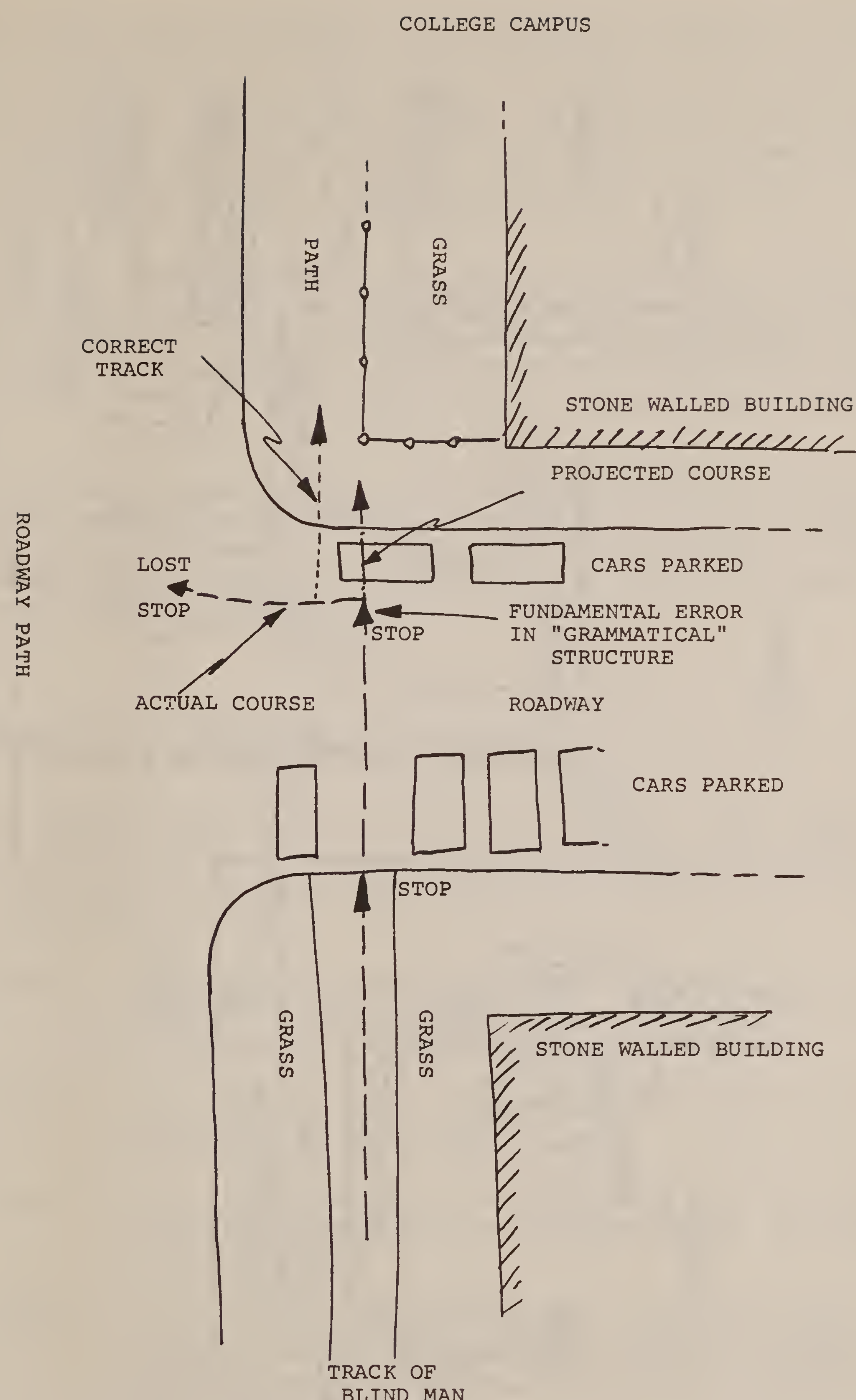
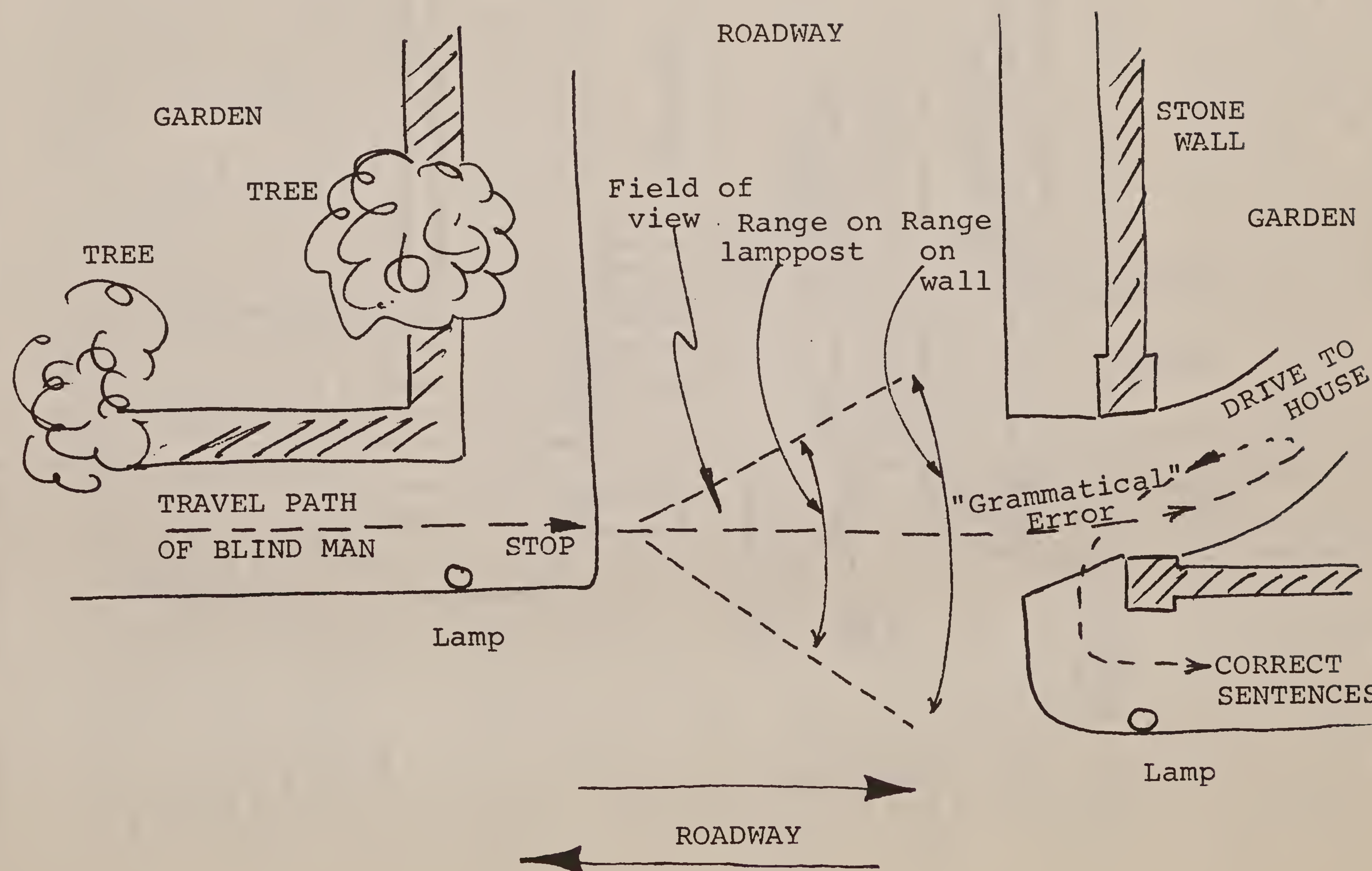


Figure 25. Example Of Error In Grammatical Structure.

Figure 26. Example Of Grammatical Error.



In the second example, the traveler stopped at the junction of the side road, crossed correctly to the opposite side of the roadway and proceeded to walk up the driveway. The wall on the right, between the path and the roadway along which traffic was traveling, was grammatically incorrect. A sensory aid must be capable of conveying this kind of grammatical error.

In both examples there is doubt about the source of error. It may have been the traveler, who was unaware of the grammar, or it may have been the aid, which did not convey the grammar. The situations were not studied since they were part of a separate, more lengthy activity.

Following this concept of the environment, studies of language structure involving syntax and semantic links may be highly relevant and provide the basis for a more detailed understanding of the place in which we walk, such as shown in Figure 27.

11. A Theory of Peripatetic Mobility

It appears now that a number of simple laws can be constructed relating to mobility which, if satisfied, enable a traveler to move from place to place with safety, ease, and grace.

Law 1. The traveler must possess the ability to propel himself safely over the terrain to be traveled at a normal walking pace.

Law 2. The traveler must be able to control the movement of his body.

Law 3. The traveler must have the ability to guide his body parallel to a boundary at a normal walking pace.

Law 4. The traveler must be able to direct the movement of his body toward a specific thing and, if required, touch it, with full control of this action.

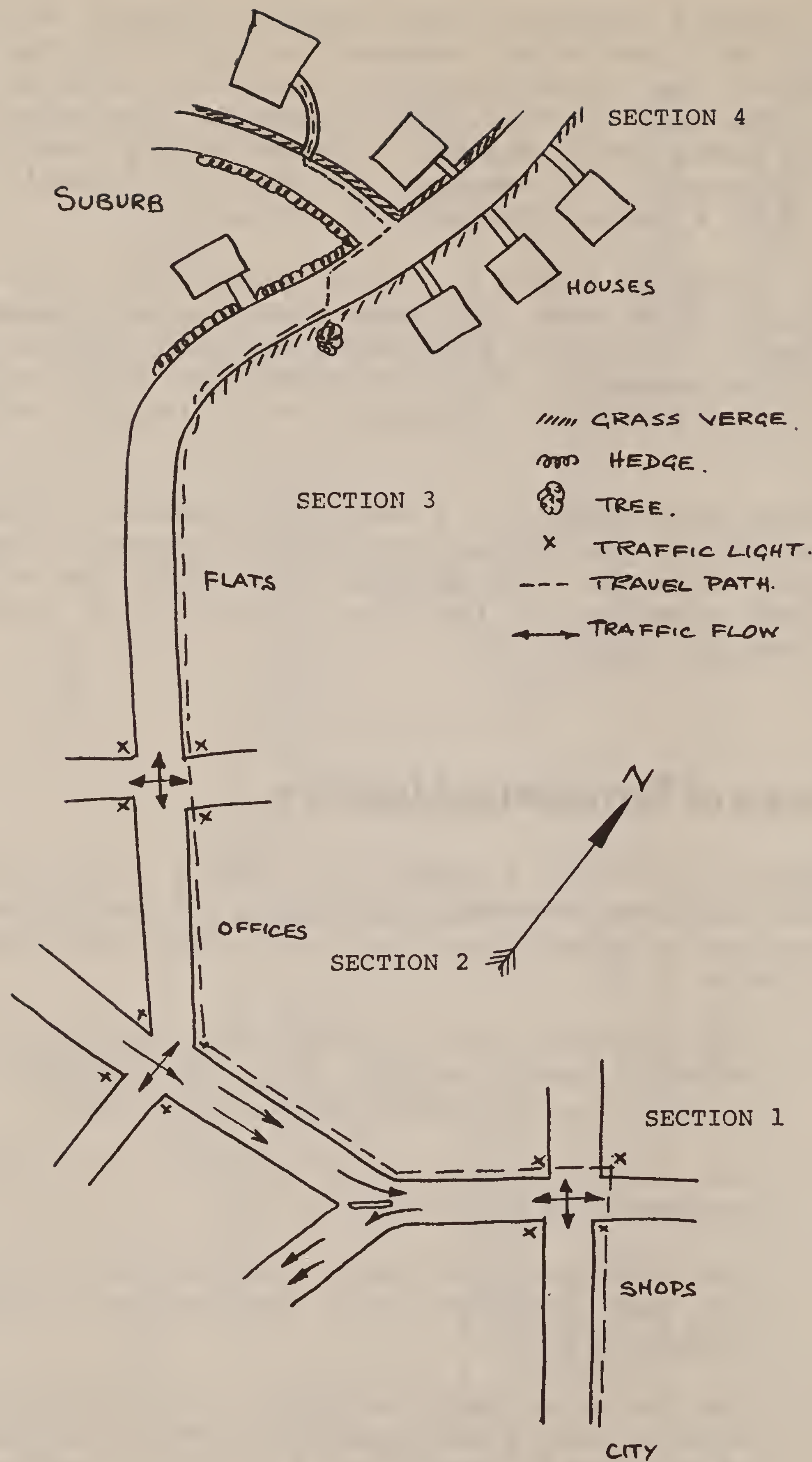


Figure 27. The Environment In Which We Walk.

Law 5. He must be able to negotiate around an object and re-establish the desired course at a normal walking pace.

Law 6. He must understand the laws of the environmental structure (environmental grammar).

Law 7. He must recognize spatial patterns forming sections of the physical environment (words and sentences of the environmental language).

Law 8. He must recognize sections of the environment as part of the world and piece these together to form a suitable route (environmental text).

Law 9. He must be able to store a cognitive map of the desired route and position himself on this map during the journey (remember the essential meaning of the text and be able to recall the main parts of this).

The blind traveler who has to rely upon his unaided sense of hearing and the conventional long cane is unable to satisfy some of these laws and in consequence finds mobility difficult. The sighted traveler has no problem satisfying all these laws, except that some have difficulty with the last one in unfamiliar situations. Any sensory aid must increase the blind pedestrian's ability to satisfy the nine laws and the degree to which this is done should be measurable.

We have seen that we can measure the ability to satisfy Laws 1 through 5, using artificial environments in controlled situations. Laws 6 through 9 are difficult to examine objectively, since they relate to the use of language; it is because of this that significant differences of opinion exist over devices and mobility performance.

11.1 Implications of Theory

A blind person moving about in a behavioral pattern like that of a sighted person would create the impression that he could "see." He would be declared blind only if he were unable to respond to questions like a sighted person (the questions may, of course, include tasks and the answers could be physical responses in the form of

execution of the task). A question is posed immediately: Is it possible to create a sensory aid which will enable a blind person (in terms of observable behavior) to move about like sighted people, and yet not be adequate to enable the same person to execute specific tasks like sighted people? One may even ask: Is it conceivable that a sensory aid could be created to enable a blind person to be mobile and yet not be able to read at normal speed, and vice versa. Answers to these questions would be of significant value in studying sensory aid systems.

We know that it is possible to create a device as an aid to reading which is of no value in a mobility setting and vice versa (e.g., the Optacon and the Binaural Sensory Aid). It is thought by a few that a cortical implant to stimulate the visual cortex would serve both purposes. There is as yet no evidence of this but it is easy to understand why the concept has scientific attraction. It would be interesting to find out just what "picture" detail would be required in order to recognize a pole, tree, shrub, railing, stone wall, hedge, traffic lights, shop window, closed door, rising steps--i.e., objects in the environment which it is important to recognize. It would also be interesting to know just how the distance to each object would be determined in a form which could be used to satisfy Laws 3 through 5.

It seems that we can now ask some specific questions and devise means for testing answers to the mobility problem which in the past we found difficulty in formulating. The goals for our research can be more specific and the interdisciplinary nature of the subject can be handled with more understanding.

12. Conclusions

A first "Theory of Mobility" has been developed and it shows that there are three important areas determining the degree to which a person may be mobile: i) motive power and body control; ii) skills in the use of motor control; iii) knowledge of the structure of the environment in a way that is not unlike understanding and using a language.

It is evident that (i) may be the domain of the physiotherapist and is not discussed in the paper; (ii) represents the area which has been of great concern to those developing sensory aids, since the skills are of prime importance; (iii) has been the prerogative of the orientation and mobility specialists, and while they may not have used the specific concepts developed in the "Theory," their work has been very closely related to it.

This approach brings together those disciplines which have in the past been thought to express opposing viewpoints, and it could lead to an increase in cooperative research. The suggested laws of mobility may be a means for determining the most appropriate methods for evaluating devices and may lead to objective measurements in an area where subjectivity has been thought to be an essential ingredient in decision-making.

A modified approach to the teaching of mobility to blind persons is seen as an inevitable outcome of the theory and more rapid learning seems feasible if the fundamental principles of the theory are applied.

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